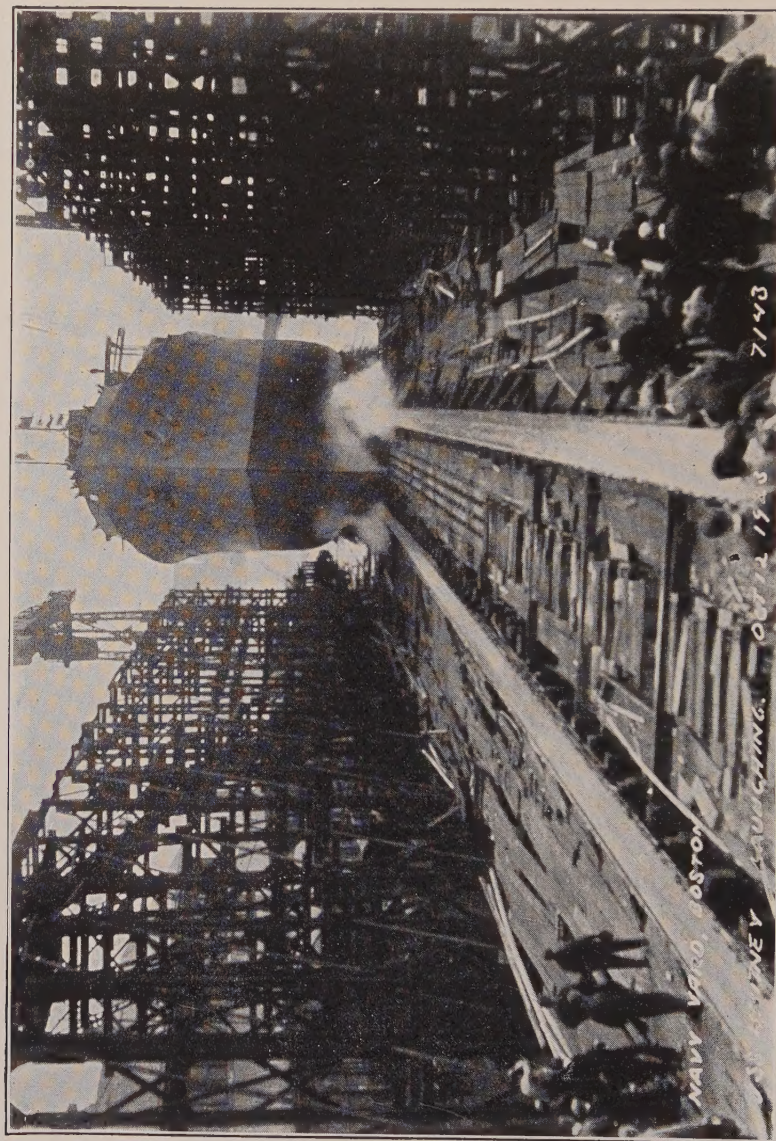




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MANUAL
OF THE
ARTS, MANUFACTURES
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SHIP LAUNCHING

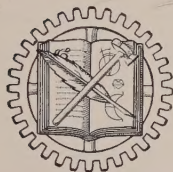
SHIP LEAVING THE WAYS.

MANUAL OF
NAVAL ARCHITECTURE

*The Fundamental Principles of Naval Architecture,
Ship-Design and Construction for Masters and Mates*

BY
GEORGE CHARLES MANNING, M.S.
Lieut. Comdr. (C C) U.S.N. Ret.

Fourth Printing



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PREFACE

The primary reason for the preparation of this work was to present the characteristics of a ship in such a way as to be of the maximum usefulness to officers of the Merchant Marine.

Most works on the subject of naval architecture and ship construction are prepared for those engaged in the design and construction of ships, not for the operating officer. There are some texts which discuss the fundamentals of buoyancy and stability and other fundamentals of ship design, but the author has not found any which are complete. They all omit some important phase of these subjects. The author has therefore endeavored to make this work cover all the features of a hull. It is out of the question to write a complete treatise on naval architecture and ship construction in two hundred pages; further, the operating officer has not the time to devote to a general detailed study of naval architecture. His business is to know his particular ship. He will know his ship much better, however, if he understands the fundamental principles of naval architecture and ship building.

To assist the operating officer to a comprehension of these fundamental principles, the author has omitted much detail of importance to the ship designer, because the inclusion of much detail would probably result in submerging the fundamental principles, and the student would be confused rather than helped. With this consideration a governing one, the author has in places been compelled to sacrifice exactness to brevity, but he believes that the officer will best handle his ship who sticks to fundamentals and studies apparent exceptions as they arise.

The author desires to express his appreciation to the U. S. Naval Institute, owners of the copyright of *Principles of Naval Architecture and Warship Construction*, and to Lieutenant Commander T. L. Schumacher, Construction Corps, U. S. Navy, the

author's collaborator in this work, for the extensive use of material therefrom. Thanks are also due to the publishers of Marine Engineering for Plate IV, which is a reproduction of material appearing in the October, 1927, issue of this publication, and to Captain Armistead Rust, U. S. Navy, and Lieutenant Commander Norman E. Merrill of the Massachusetts State Nautical School for reading and criticizing the manuscript.

G. C. M.

Boston, Mass.

November, 1929

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TO THE STUDENT

There is presented in this book a discussion of the principles of naval architecture and ship construction. Only the fundamentals are included; detail has been religiously cut out. To develop into the highest type of officer, you will need to know all that is given herein. Of course, no general treatment can tell an officer as much about his particular ship as he can learn by intelligent observation. From a study of this work and the portfolio of plans furnished the master of a ship, one can learn a great deal more about his ship than he could from his undirected observations.

In the presentation of the subject matter, reference to difficult mathematics has been avoided as far as possible. Anyone with a knowledge of elementary algebra and the trigonometry requisite for navigation should be able to follow through the very simple mathematical treatments given. The results of such discussion are invariably stated in words also. In the solution of problems the mathematics from which the formulas were derived can be ignored and the problems solved simply as exercises in arithmetic. No glossary of terms used in naval architecture and ship construction is given. The index gives the page and article numbers of the definitions of such terms.

Through a study of fundamental principles, learn to know thoroughly your own ship.

MASTERS' AND MATES' MANUAL OF NAVAL ARCHITECTURE

CHAPTER I

BUOYANCY

The beginner may find this opening chapter dull reading and unduly burdened with mathematical computations. The author knows of no remedy for this condition due to the necessity of defining the terms used in subsequent chapters and of presenting a logical introduction to the discussion of the vital subject of stability of ships. The author, however, recommends that the reader using this work for self-instruction do not spend an undue amount of time on this chapter but after reading it carefully go on with his study of the subsequent chapters and refer back to this chapter as necessary.

SECTION A—DEFINITIONS

1. Waterlines. The surface of a ship's hull has curvature in three dimensions. It is therefore as impossible to represent the true shape of this surface by the usual devices of orthographic projection as it is to show the true shape of a propeller blade or any other helical surface in a two dimensional drawing. The device universally adopted to give exact information regarding the shape of a ship's hull is to intersect this surface by planes. The lines of intersection between these planes and the hull have curvature in two dimensions only. They may therefore be drawn in their true shape on paper. One series of planes is passed parallel to the designer's waterline of the ship. The spacing of these planes depends on the draft of the ship; there are usually five or more such planes below the designer's waterline and three or more above it. Since a hull is always symmetrical with respect to the longitudinal vertical centerline plane, only the curve for one side is drawn. These curves are drawn on the centerline of the ship as a common base line. Such curves are called **waterlines** although it may be impossible for the ship ever to float at the drafts corresponding to certain of them. The waterlines are marked "W.L." in **Plate I**. The base line is the **zero waterline**. The waterline of

the ship when floating at its designed draft is the **designer's waterline**.

2. Stations. Another series of planes is passed perpendicular to the longitudinal vertical centerline plane of the ship and the waterline planes. These planes cut curves which show the outline of transverse sections of the ship at various points along its length. The curves obtained are projected orthographically on a plane outside of the ship and the conventional method is to draw the half view of bow stations on the right and that of stern sections on the left to reduce the number of curves on the drawing. The stations are marked with their numbers on **Plate I**. The station at the midlength, Station No. 10 of **Plate I**, is known as the **Midship Section** or **Dead Flat** and is indicated by the symbol ☒.

3. Buttocks. A third series of planes is passed parallel to the longitudinal vertical centerline plane, and therefore perpendicular to the planes of the waterlines and stations. Consider the waterlines as showing the plan view of the ship, the stations as showing an end view of the ship, the buttocks (as this third set of curves is called) show a side view of the ship. There are usually four such planes passed at equal intervals from the plane of symmetry, which plane is the **zero buttock**. The buttocks are marked "Butt." on **Plate I**.

4. Diagonals. In addition to the above three series of planes which are mutually perpendicular to each other, a fourth group of about three planes known as diagonals is usually passed. These planes are perpendicular to the planes of the stations and inclined to those of the waterlines and buttocks. They are approximately perpendicular to the surface of the hull where they cut it. The bilge diagonal which is so named because it intersects the hull at the turn of the bilge, is marked "Bilge Diagonal" on **Plate I**.

5. Line drawing. A drawing like **Plate I** showing the lines of a ship which may be considered to have been obtained in the above manner is termed by naval architects, the **Line Drawing**; the view showing the true shape of the waterlines the **Half Breadth Plan**;



PLATE I.—SHIPS' LINES.

that showing the true shape of the stations, the **Body Plan**; and that showing the true shape of the buttocks, the **Sheer Plan**. In addition to these, there is added in the half breadth plan, a plan view of the main and sometimes other decks; in the body plan the curve showing the height above the base line of the deck edge; and in the sheer plan lines showing the curvature in a vertical plane of the centerline and edge of the deck, and the contour of the ship at stem and stern. The deck edge is a three dimensional curve and projects as a curve in all three views. The rest of the lines by their process of generation are plane curves, so that they appear curved in only one view and as straight lines (planes seen on edge) in the other two.

6. Base line and perpendiculars. The **base line** is the line from which vertical distances are measured. It is usually a line coincident with the top of the flat keel.

The **forward perpendicular**, FP of **Plate I**, is a perpendicular to the base line, passing through the intersection of the contour of the stem and the designer's waterline.

The **after perpendicular**, AP of **Plate I**, is a perpendicular to the base line, passing through the intersection of the contour of the sternpost and the designer's waterline.

7. Deck lines; Sheer lines. **Deck lines** are the projections of the curves of the deck edges on the half breadth plan. **Deck lines at side** are lines showing the projections of the deck edges on the body plan and sheer plan. **Plate I** shows these lines for the main and second decks.

Sheer lines are those showing the curvature in a vertical plane of lines of rail, deck edge and deck at center.

8. Length (L). **Length between perpendiculars** is the designer's length because it is the length of the part of the ship below water, and as far as displacement and propulsion are concerned, the part below water is the ship. It is the distance, measured parallel to the base line, between the forward and after perpendiculars. **Length over all** is the length from the extreme point of stem to extreme point of stern.

9. **Breadth; Camber.** **Breadth molded** is the breadth of the ship at its widest point measured to the outside surface of the frames. **Breadth extreme** is the breadth measured to the outside surface of fenders or plating.

Camber is the curvature, convex up, given to decks primarily to facilitate drainage.

10. **Draft (D).** Draft at any point is the vertical distance from the surface of the water to the bottom of the ship, at that point. When measured at or near the stem it is denoted as **draft forward** and when measured at or near the sternpost as **draft aft**. The **mean draft** is the mean of drafts forward and aft. Most ships are designed to have the same draft forward and aft. Such a ship is called an even keel ship because the keel line is horizontal when she is floating at her designed draft. When such a ship has a difference between her drafts forward and aft she is said to be "out of trim." If the draft forward is the greater, she is "down by the head" or "trimmed by the head" and when the draft aft is greater, she is "down by the stern" or "trimmed by the stern." **Change of trim** is the **sum** of the changes of draft forward and aft. If on a ship drawing 20 ft. forward and aft changes are made to change these drafts to 19 ft. 6 in. forward and 20 ft. 6 in. aft, the change of trim is **one foot**. When the ship is **designed** to have a greater draft aft than forward, she is said to be designed with a **drag** and the difference between drafts aft and forward when floating at the designer's waterline is the **drag**. Ships are seldom designed to have greater draft forward than aft. In the case of ships designed with a drag the designer's waterline is inclined to the base line. In such ships the stations are taken perpendicular to the base line and the waterlines parallel to it; the latter are therefore **not parallel** to the designer's waterline.

The maximum draft to which merchant ships may be loaded without voiding their insurance is indicated by a mark on the side of the ship at the midship section. This is known as the Plimsoll mark from the author of the legislation which first required the maximum draft of ships to be marked on them.

11. Depth; Dead rise. **Depth** is the vertical distance from the top of the keel **at the centerline** to the top of the deck beams of the highest complete watertight deck **at the side**.

Dead rise or rise of floor is the amount the tangent to the bottom of the ship at the midship section rises above a horizontal line at the top of the keel in the half breadth of the ship.

12. Freeboard; Sheer; Reserve of buoyancy. **Freeboard** is the vertical distance from the water to the weather deck edge at any point in the length of the ship, i.e., the amount the ship may sink before water begins to come on the deck at that point. The freeboard at bow, stern and amidships is usually indicated or stated.

Sheer is the excess of freeboard forward or aft over that amidships.

Reserve of buoyancy is the amount of buoyant volume a ship may lose before sinking. It is equal to the watertight volume above the waterline and below the highest watertight deck.

13. Displacement and tonnage. The displacement of a ship is the weight of the water displaced by the ship floating freely in the water. By the Principle of Archimedes the weight of water displaced by a floating body is equal to the weight of that body. Therefore, the displacement of a ship is equal to its weight. When we say that the displacement of the *Leviathan* is 50,000 tons, we mean that she **weighs** 50,000 long tons of 2240 pounds.

The tonnage of warships always refers to their displacement. In dealing with merchant ships, other tonnages are equally important. The **light weight** of the ship is the weight of the ship fully equipped with propelling machinery and equipment but without fuel or cargo. **Deadweight** is the number of tons of stores, fuel and cargo a ship can carry when loaded down to her drafts. It is numerically equal to the difference between the full load displacement and the light weight of the ship.

$$\text{Gross tonnage} = \frac{\text{Volume of ship below main deck in cubic feet}}{100}$$

$$\text{Net tonnage} = \frac{\text{Volume of cargo space in cubic feet}}{100}$$

In other words, gross and net tonnages are measures of cubic capacity rather than of weight.

In merchant ships of usual form the gross tonnage is about 60% of the displacement tonnage.

The subject of tonnage is discussed at greater length in Chapter V.

14. Center of buoyancy and center of gravity of ship; Center of flotation. The geometric center of gravity of the volume of displacement is the **center of buoyancy**, designated by C.B. or B. Just as the entire weight of the ship may be considered in calculations to be concentrated at its center of gravity, so the force of buoyancy may be considered as acting at the center of buoyancy. The center of gravity of the ship, designated by C.G. or G. is practically certain not to coincide with the center of buoyancy due to the non-homogeneity of the ship and the fact that a large part of it is above the water.

The center of gravity of the waterline at which the ship is floating is called the **center of flotation**.

15. Metacenter. The line of action of the force of buoyancy supporting a ship is vertically up through the center of buoyancy. If the ship is given a transverse inclination the shape of the sub-

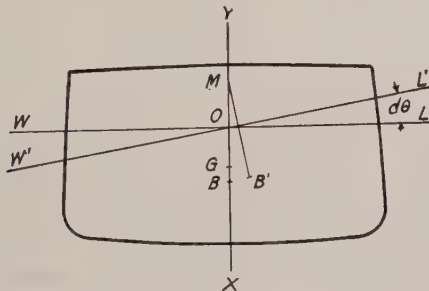


FIG. 1.—TRANSVERSE METACENTER.

merged portion changes; in Fig 1 from WOL to W'OL'. Therefore the C.B. moves from B to B'. The line of action of the buoyancy when the ship is inclined intersects the line of action of the buoyancy when the ship is erect at M. With most ships, if the

transverse inclination does not exceed about 10° , the point of intersection of the old vertical through B and the new vertical through B' will be found to be at the same place regardless of the inclination. This point is called the **metacenter**, M, or more accurately, the transverse metacenter. Stated briefly: **for small angles of inclination the force of buoyancy acts through the same point, which point is the metacenter.**

If the ship is given a small longitudinal inclination a similar point M' (see Fig. 2) will be determined. This point is the **longi-**

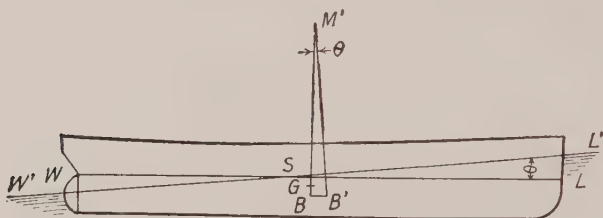


FIG. 2.—LONGITUDINAL METACENTER.

tudinal metacenter. The importance of the metacenter in ship calculations will be brought out in Chapter II.

16. Coefficients of fineness. In the early stages of design certain so-called **coefficients of fineness** are employed for the purpose of comparing properties of the new design and determining the principal dimensions.

(a) The **block coefficient** (α) is the ratio between the volume

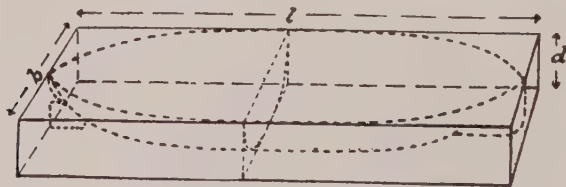


FIG. 3.—BLOCK COEFFICIENT.

of displacement (V) and that of a rectangular block having edges equal respectively to the length (L), beam (B) and draft (D).

$$\alpha = \frac{V}{L B D} \text{ See Fig. 3.}$$

(b) The **prismatic** also called the **cylindrical** and **longitudinal coefficient** (δ) is the ratio between V and the volume of a cylinder having the same length as the ship and section equal to the area of the midship section below the designer's waterline (A_{M})

$$\delta = \frac{V}{A_{\text{M}} L} \text{ See Fig. 4.}$$



FIG. 4.—PRISMATIC COEFFICIENT.

(c) The **midship section coefficient** (β) is the ratio between A_{M} and a rectangle having sides equal to B and D .

$$\beta = \frac{A_{\text{M}}}{B D}$$

(d) The **coefficient of fineness of a waterline** (γ) is the ratio between its area and the circumscribing rectangle. For the designer's waterline this is:

$$\gamma = \frac{A_{\text{d.w.l.}}}{BL}$$

SECTION B—CALCULATION OF AREAS, VOLUMES AND MOMENTS

17. Methods employed. A ship is enclosed in curved surfaces. The solid enclosed by these surfaces is not one of the simple geometric solids such as the sphere, cylinder or prism for which simple formulæ are available to compute the volume and center of gravity. Further the curves obtained by plane intersections (waterlines, stations, etc.) are in general **not** curves for which simple algebraic equations can be written. These curves do not therefore lend themselves to exact integration. Approximate methods of integration must therefore be employed. The formulæ used in ship calculations are merely applications of approximate integration formulæ. Since exact formulæ cannot be used, the results obtained are not

exact. This lack of mathematical exactness is a characteristic of all engineering calculations as differentiated from laboratory work. In view of the unavoidable errors in the basic data, excessive pains to secure exact results from the calculations are not warranted, since even with mathematically exact formulæ, the result could be no more accurate than the data from which it was obtained. Where alternate methods of calculation are available, the results obtained will be only in **approximate** agreement.

18. Simpson's first rule. One of the rules of mensuration used a great deal in England and to a less extent here, is called **Simpson's First Rule**. To find an area such as that below we divide the base AB into any **even** number of **equal parts** and erect perpendiculars to the base at these points. The area ABCD between the curve and the base is approximately:

$$A = \frac{h}{3} (y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + 4y_5 + y_6)$$

or in general

$$A = \frac{h}{3} (y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + \dots + 4y_{n-1} + y_n),$$

where n is **even**.

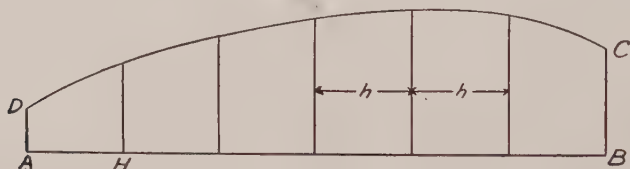


FIG. 5.—ORDINATES FOR COMPUTATIONS.

19. Simpson's Second Rule. Another rule used somewhat less is Simpson's Second Rule. To find an area such as that above, we divide the base AB into a number of parts divisible by three and erect perpendiculars to the base at these points. The area ABCD between the curve and the base is approximately:

$$A = \frac{3h}{8} (y_0 + 3y_1 + 3y_2 + 2y_3 + 3y_4 + 3y_5 + y_6)$$

or in general

$$A = \frac{3h}{8} (y_0 + 3y_1 + 3y_2 + 2y_3 + 3y_4 + \dots + 3y_{n-1} + y_n)$$

where n is divisible by three.

20. Trapezoidal rule. Another rule, the one principally used in ship calculations in the U. S. Navy, is known as the **trapezoidal rule**. To find the area ABCD by this rule we divide AB into **any** number of **equal parts** and at the points of division erect perpendiculars.

$$A = h (\frac{1}{2}y_0 + y_1 + y_2 + y_3 + y_4 + y_5 + \frac{1}{2}y_6)$$

or in general

$$A = h (\frac{1}{2}y_0 + y_1 + y_2 + \dots + y_{n-1} + \frac{1}{2}y_n),$$

where n is **any integer**.

21. Other rules; Fractional intervals; Volumes. There are other rules having certain special applications but they are relatively little used. They may be found in any advanced textbook on naval architecture.

It frequently happens that the curvature at the ends is considerably greater than over the other parts of the curve. In such cases the accuracy of the computation is increased if in such regions the number of ordinates is doubled or quadrupled by reducing the interval between ordinates to one half or one fourth that used throughout the rest of the curve.

The volumes of three dimensional spaces are similarly computed by using as ordinates the areas of equally spaced planes.

22. Computation of an area. To illustrate the method employed in ship calculations, let us find the area ABCD by Simpson's first rule, Simpson's second rule and the trapezoidal rule. **In ship calculations the linear unit is the foot and the unit of weight the long ton of 2,240 lbs.**

By Simpson's
First Rule

Ordinate	Multiplier	Function of Area
6	1	6
13	4	52
15	2	30
16	4	64
17	2	34
16	4	64
14	1	14
Sum		264

By Simpson's
Second Rule

Ordinate	Multiplier	Function of Area
6	1	6
13	3	39
15	3	45
16	2	32
17	3	51
16	3	48
14	1	14
Sum		235

By Trapezoidal
Rule

Ordinate	Multiplier	Function of Area
6	$\frac{1}{2}$	3
13	1	13
15	1	15
16	1	16
17	1	17
16	1	16
14	$\frac{1}{2}$	7
Sum		87

$h = 12$ ft.

By Simpson's First Rule $A = \frac{1}{3} \times 264 = 1056$ sq. ft.

By Simpson's Second Rule $A = \frac{2}{3} \times 12 \times 235 = 1057.5$ sq. ft.

By Trapezoidal Rule $A = 12 \times 87 = 1044$ sq. ft.

23. Computation of a volume. The areas of equally spaced planes in an oil tank are 20, 35, 55, 65, 70, 60 and 44 sq. ft. respectively. The distance between planes is 12 ft. How many gallons of oil will it hold? There are 7.5 gals. per cu. ft.; allow 4% of volume for deductions.

By Simpson's
First Rule

Ordinate	Multiplier	Function of Volume
20	1	20
35	4	140
55	2	110
65	4	260
70	2	140
60	4	240
44	1	44
Sum		954

By Simpson's
Second Rule

Multiplier	Function of Volume
1	20
3	110
3	165
2	130
3	210
3	180
1	44
	859

By Trapezoidal
Rule

Multiplier	Function of Volume
$\frac{1}{2}$	10
1	35
1	55
1	65
1	70
1	60
$\frac{1}{2}$	22
	317

By Simpson's First Rule $V = \frac{1}{3} \times 954 = 3816$ cu. ft.

By Simpson's Second Rule $V = \frac{2}{3} \times 12 \times 859 = 3865.5$ cu. ft.

By Trapezoidal Rule $V = 12 \times 317 = 3804$ cu. ft.

The problem will be completed using the cubical contents given by Simpson's First Rule.

If we allow 4% for deductions, the net contents of the tank is 96% of 3816 cu. ft. or 3663 cu. ft. and it will hold 3663×7.5 equals 27,473 gal.

24. Computation of displacement. The above problems illustrate the method of calculating the displacement of a ship. The areas of the transverse stations are first calculated by measuring the widths at the various waterlines. Then the volume of displacement is obtained using the areas thus found as ordinates. The displacement of the ship in salt water is obtained by dividing the volume in cubic feet by 35 since 35 cu. ft. of sea water weigh one ton. The displacement in fresh water is similarly obtained by dividing the volume in cubic feet by 36 since 36 cu. ft. of fresh water weigh one ton. The displacement may also be determined by first calculating the areas of the various waterlines and then using these areas as ordinates.

The displacements of a ship corresponding to each waterline are computed and a curve of displacements against drafts drawn.

25. Location of center of gravity of an area. To find the center of gravity of an area we first find its moment about any reference axis and then divide this moment by the area to ascertain the perpendicular distance of the center of gravity from the axis of reference. To find the location of the center of gravity of ABCD of Fig. 5, we may determine its distance from AB and AD or from AB and y_3 . The latter is more usual because we can tell from an inspection of the figure that the C. G. will lie near y_3 . In the first case, the moments of the elements of area have the same sign; in the latter case, we take the difference between the moments of the elements of area on each side of y_3 . The net moment of the area about y_3 is this difference. The center of gravity will lie between y_3 and y_4 if the moment of the right half of ABCD is the greater and between y_3 and y_2 if that of the left half is greater. To show the method the distance of the center of gravity from both AD and y_3 will be calculated. The moment of an ordinate, say y_1 , about AD is $y_1 \times AH = y_1 \times h$. Simi-

larly that about y_3 is $y_1 \times 2h$. We may use either of Simpson's rules or the trapezoidal rule to compute this moment, but, of course, we must use the same rule in calculating the moment about both axes chosen. We shall use Simpson's First Rule.

Or-	Multi-	Function	Arm	Function	Arm (Moment	Function
dinate	plier	of Area	(Moment	of Moment	about y_3)	of Moment
			about AD)			
6	1	6	0×12	0	$(+) 3 \times 12$	216
13	4	52	1×12	624	$(+) 2 \times 12$	1248
15	2	30	2×12	720	$(+) 1 \times 12$	360

It will be noted that the distance between ordinates, 12 ft., enters as a common factor in computing each "Function of Moment." Obviously the calculation would be simplified if this factor were reserved to the end and this is usually done, so that instead of the figures given above we have

Or-	Multi-	Function	Arm	Function	Arm	Function
dinate	plier	of Area	(Moment	of Moment	(Moment	of Moment
			about AD)		about y_3)	
6	1	6	0	0	3	18
13	4	52	1	52	2	104
15	2	30	2	60	1	30
						<u>+ 152</u>
16	4	64	3	192	0	0
17	2	34	4	136	1	34
16	4	64	5	320	2	128
14	1	14	6	84	3	42
						<u>— 204</u>
		264		844		<u>— 52</u>

$$M_{AD} = \frac{12}{3} \times (844 \times 12)$$

$$A = \frac{12}{3} \times 264$$

$$C.G._{AD} = \frac{\frac{12}{3} \times 844 \times 12}{\frac{12}{3} \times 264} = 38.36 \text{ ft. from AD}$$

$$M_{y_3} = \frac{12}{3} \times \{ (-) 52 \times 12 \}$$

$$\begin{aligned} \text{C.G.}_{y_3} &= \frac{-\frac{12}{3} \times 52 \times 12}{\frac{12}{3} \times 264} = 2.36 \text{ ft. to right of } y_3 \\ &= 36 + 2.36 = 38.36 \text{ ft. from AD} \end{aligned}$$

To completely locate the center of gravity of ABCD we must determine the distance of this point from AB.

Ordinate	Multiplier	Function of Area	Arm	Function of Moment
6	1	6	$\frac{6}{2}$	18
13	4	52	$\frac{13}{2}$	338
15	2	30	$\frac{15}{2}$	225

It will be noted that the arm in each case is half the ordinate. It will obviously simplify matters to reserve the factor $\frac{1}{2}$ to the end and apply the rule of mensuration to the **square** of the ordinate.

Ordinate	Square of Ordinate	Multiplier	Function of Moment
6	36	1	36
13	169	4	676
15	225	2	450
16	256	4	1024
17	289	2	578
16	256	4	1024
14	196	1	196
			3984

$$M_{AB} = \frac{12}{3} \times 3984 \times \frac{1}{2}$$

$$\text{C.G.}_{AB} = \frac{\frac{12}{3} \times 3984 \times \frac{1}{2}}{\frac{12}{3} \times 264} = 7.55 \text{ ft.}$$

The center of gravity of ABCD is 38.36 ft. from AD and 7.55 ft. from AB.

26. Location of center of gravity of a volume. To determine the location of the center of gravity of a volume we intersect it by equally spaced planes and find the area and location of

center of gravity of each of these planes just as was done for ABCD in *Art. 25*. Using the areas of these planes as ordinates we can compute the volume, as shown in *Art. 23* and the three co-ordinates of the center of gravity in a manner similar to that for determining the two co-ordinates of the center of gravity of ABCD in *Art. 25*. The method is best shown by an example.

Example: Determine the location of the center of gravity of the oil tank of *Art. 23* with reference to (a) y_3 , (b) the tank top, (c) AB. The distances of the centers of gravity of the equally spaced planes below the tank top are 6.0, 5.8, 5.5, 5.1, 4.6, 4.4 and 4.3 ft., respectively, and the horizontal distances of their C.G.'s from AB are 4.0, 4.5, 5.2, 6.1, 7.0, 7.5 and 7.8 ft., respectively.

The solution is made in one tabulation. As an illustration, consider y_2 .

Moment about $y_3 = y_2 \times h$.

Moment about tank top $= y_2 \times 5.5$

Moment about AB $= y_2 \times 5.2$.

Ordinate	Multiplier	Function of Volume	Arm (Moment about y_3)	Function of Moment	Arm (Moment about tank top)	Function of Moment	Arm (Moment about AB)	Function of Moment
20	1	20	3	60	6.0	120	4.0	80
35	4	140	2	280	5.8	812	4.5	630
55	2	110	1	110	5.5	605	5.2	572
				<u>+ 450</u>				
65	4	260	0	0	5.1	1326	6.1	1586
70	2	140	1	140	4.6	644	7.0	980
60	4	240	2	480	4.4	1056	7.5	1800
44	1	44	3	132	4.3	189	7.8	343
				<u>— 752</u>				
		954		<u>— 302</u>		4752		5991

$$M_{y_3} = \frac{12}{3} \times 302 \times 12$$

$$C.G._{y_3} = \frac{\frac{12}{3} \times 302 \times 12}{\frac{12}{3} \times 954} = 3.80 \text{ ft. to right of } y_3$$

$$M_{T.T.} = \frac{12}{3} \times 4752$$

$$C.G._{T.T.} = \frac{\frac{12}{3} \times 4752}{\frac{12}{3} \times 954} = 4.98 \text{ ft. below tank top}$$

$$M_{AB} = \frac{12}{3} \times 5991$$

$$C.G._{AB} = \frac{\frac{12}{3} \times 5991}{\frac{12}{3} \times 954} = 6.28 \text{ ft. from AB}$$

The center of buoyancy is the center of gravity of a volume, the volume of displacement. Its longitudinal and vertical locations for various drafts are similarly computed. Since the ship is symmetrical with respect to the vertical longitudinal centerline plane, this plane contains the center of buoyancy, and its position is definitely fixed when we know its height above the base line and its horizontal distance from the midship section. Curves of the vertical and longitudinal positions of the center of buoyancy are plotted against drafts in feet.

SECTION C—DISPLACEMENT AND OTHER CURVES

27. List of curves

1. Displacement in salt water.
2. Displacement in fresh water.
3. Vertical position of center of buoyancy.
4. Longitudinal position of center of buoyancy.
5. Areas of waterlines.
6. Longitudinal position of center of gravity of waterlines.
7. Tons per inch immersion.
8. Area of midship section.
9. Outline of midship section.
10. Height of transverse metacenter above base line.

1. Displacement in salt water (35 cu. ft. = 1 ton).
2. Displacement in fresh water (36 cu. ft. = 1 ton).
3. Vertical position of center of buoyancy.
4. Longitudinal position of center of buoyancy.
5. Areas of water lines; 1 ton = 2 sq. ft.
6. Longitudinal position of c.g. of water lines; 100 tons = 1 ft.
7. Tons per inch immersion; 100 tons = 1 ton.
8. Area of midship section; 4 tons = 1 sq. ft.
9. Outline of midship section.

10. Height of transverse metacenter above base.
11. Longitudinal metacentric radius; 5 tons = 1 ft.
12. Moment to change trim 1 inch; 5 ton = 1 ft. ton.
13. Correction to displacement for trim; 200 tons = 1 ton.
14. Area of wetted surface; 1 ton = 4 sq. ft.
15. Curve of areas of sections to DWL; 1 ft. (on draft scale) = 400 sq. ft.
16. Outboard profile showing frames and stations.
17. Diagonal for CB and transverse metacenter above base line.

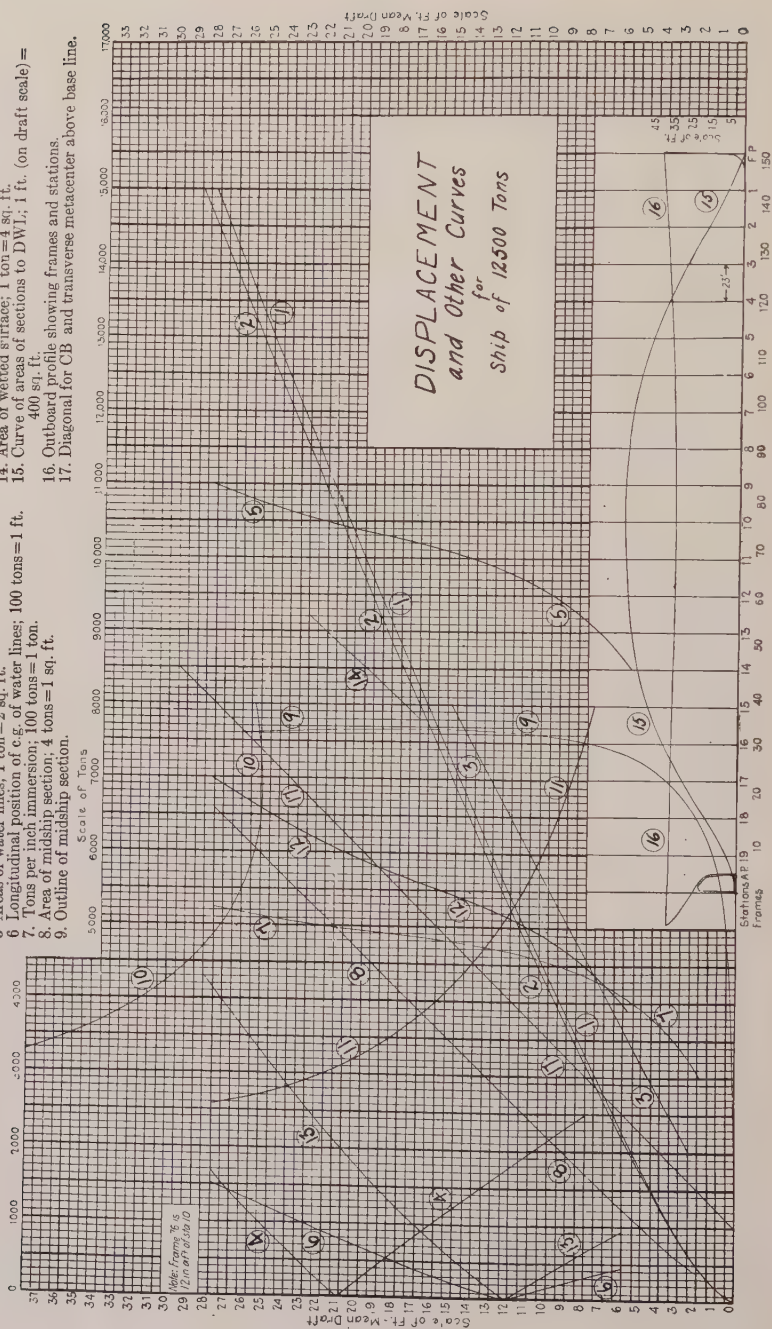


PLATE II.—DISPLACEMENT AND OTHER CURVES

11. Longitudinal metacentric 'radius (BM').
12. Moment to change trim one inch.
13. Correction to displacement when vessel is trimmed one foot by the stern.
14. Area of wetted surface.
15. Curve of sectional areas up to normal load waterline.
16. Outboard profile showing relative location of frames and sections.

The primary function of the displacement curves, **Plate II**, is to permit a ready means of determining the displacement of the ship by measuring her draft, the ordinates are therefore taken as drafts in feet and the abscissæ displacements in tons. The abscissæ apply directly only to the first two curves, displacements in salt and fresh water. The abscissæ of the other curves are different and are obtained from the scale of tons by applying the proper scale factor as given for each curve; the ordinates, draft in feet, are the same for all curves.

Plate III is a Deadweight Scale. This has some of the information given on **Plate II** in a much more available form for the operating officer than **Plate II**. It should be carefully studied until thoroughly understood as it is in almost daily use by the operating officer of a ship carrying freight.

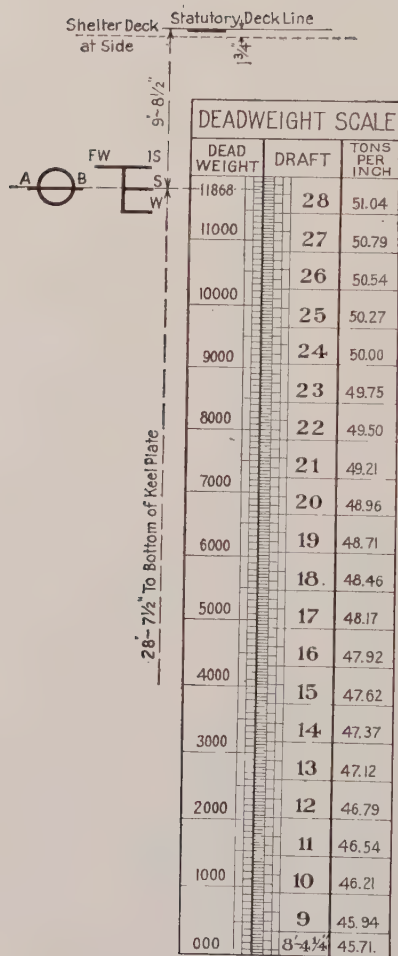
28. Method of using curves. The method of using these curves can best be shown by illustrative examples.

(a) Curve 1. What is the displacement in salt water of the ship of **Plate II** when her draft is 24 feet?

Enter the scale of drafts, vertical scale, and locate the horizontal line passing through 24 feet. Follow this line across until it intersects curve 1, displacement in salt water, and read displacement on horizontal scale directly above intersection of these two lines, 12,410 tons.

(b) Curve 2. What is the displacement in fresh water of the ship of **Plate II** when she draws 25 feet?

Enter scale of drafts with 25 feet and note intersection of horizontal line through this point and curve 2, displacement in



Light Displacement 4078 Tons

PLATE III.—DEADWEIGHT SCALE.

fresh water. Read this displacement, 12,660 tons, directly above this intersection.

(c) Curves 3 and 4. The draft of the ship of Plate II is 23 feet. Locate the center of buoyancy.

First find the height of the center of buoyancy above the base line. Follow the horizontal line indicating 23 feet draft until it intersects the straight line which is drawn from the origin at an angle of 45° to the axes marked "**Diagonal for Center of buoyancy and Transverse Metacenter above Base.**" Follow vertical line through this intersection downward until curve 3 is met. Follow horizontal line through this last intersection back to draft scale and read height of center of buoyancy above base line as 12 ft. 8 in.

To find the longitudinal position of the center of buoyancy follow horizontal draft line until it intersects curve 4. It will be noted that curve 4 has two branches with an abscissa of zero at a draft of 21 feet. For drafts less than 21 feet the center of buoyancy is forward of station No. 10; for greater drafts, it is aft of station No. 10. This is characteristic of all ships although, of course, the draft at which the C.B. is at the midship section varies for each particular ship. In the examples given we read 420 tons above the intersection of the 23-foot draft line and the upper branch of the curve. The scale factor given is 500 tons equals 1 foot. Therefore C.B. is $\frac{420}{500} = 0.84$ ft. aft of station No. 10.

Therefore C.B. is 12.67 ft. above base line and 0.84 ft. aft of station No. 10.

(d) Curve 5. What is the area of the waterline of the ship of Plate II when its draft is 20 feet?

Follow the horizontal line indicating 20 feet draft until it intersects curve 5. Read 10,360 tons on horizontal scale vertically above this intersection. Note scale factor given on curve, i.e. 1 ton = 2 sq. ft. Therefore area of waterline is $2 \times 10,360 = 20,720$ sq. ft.

(e) Curve 6. When the ship of Plate II has a draft of 21 feet, where is the center of flotation?

The center of flotation is the center of gravity of the water-

line. Therefore note intersection of 21 ft. draft line and curve 6. In this case also, it is noted that curve 6 has two branches with a zero ordinate at 12 ft. draft. This is a usual characteristic of this curve. For drafts less than 12 feet the center of flotation is forward of station No. 10; for greater drafts, aft of it. In the example given the 21 ft. draft line meets the upper branch of curve 6 giving a value of 775 tons. The scale factor is 100 tons equals 1 foot. Therefore the center of flotation is $\frac{775}{100} = 7.75$ ft. aft of station No. 10.

(f) **Curve 7.** Values are taken from this curve as in paragraph (d); for 22 ft. draft the tons per inch is $\frac{5010}{100} = 50.1$ tons.

(g) **Curve 8.** Values are taken from this curve as in paragraph (d); for 24 ft. draft the area of the midship section is $\frac{5600}{4} = 1400$ sq. ft.

(h) **Curve 9.** This curve has no use except to show the shape of the midship section.

(i) **Curve 10.** When the ship of Plate II draws 20 feet, what is the height of the transverse metacenter above the base line?

Note the intersection of the given draft line and the "Diagonal for Center of Buoyancy and Transverse Metacenter above Base." Next follow vertically upward from this point to curve 10 and note reading on **draft** scale corresponding to this last intersection. In this case 25 ft. 10½ in. Therefore the transverse metacenter is 25.88 ft. above the base line.

(j) **Curve 11.** Values are taken from this curve as in paragraph (d); for 21 ft. draft the longitudinal metacentric radius is $\frac{3135}{5} = 627$ ft.

(k) **Curve 12.** Values are taken from this curve as in paragraph (d); for 26-ft. draft the moment to change trim one inch $\frac{6660}{5} = 1332$ ft. tons.

(l) **Curve 13.** Curves 1 and 2 are plotted on the assumption that the ship has the same draft forward and aft. Suppose the ship of Plate II is drawing 18 ft. forward and 20 ft. aft. The

displacement in salt water corresponding to her mean draft of 19 ft. is 9400 tons. But this is not her true displacement because the **emerged** wedge forward does not have the same volume as the **immersed** wedge aft. Curve 13 gives the correction to displacement for one foot trim by the stern.

This curve like 4 and 6 has two branches. For drafts greater than 12 ft, the correction to displacement is additive for trim by the stern and subtractive for trim by the head; for less drafts, the reverse is true. In the incident case, 19 feet mean draft, the correction is $\frac{1460}{200} = 7.3$ tons increase in displacement for one foot trim by the stern. The actual trim is two feet by the stern; therefore, the true displacement in salt water in this example is $9400 + 2 \times 7.3 = 9415$ tons.

(m) **Curve 14.** Values are taken from this curve as in paragraph (d); for 20 ft. draft the area of the wetted surface is $8510 \times 4 = 34,040$ sq. ft.

When the displacement curves of a vessel are not available an approximate computation of the wetted surface may be made by the following formula of Rear-Admiral Taylor, (CC), U. S. Navy.

$$S = C\sqrt{WL}$$

where S = wetted surface in sq. ft.

C = constant varying with the ratio of beam to draft and having a mean value of 16.65.

W = displacement in tons

L = length in feet

(n) **Curve 15.** From this curve the area of a section up to the normal load line at any point in the ship's length may be obtained. This area for frame 50 is 2240 sq. ft.

(o) **Curve 16.** This curve shows the shape of the centerline plane of the ship and the relative location of stations used for fairing and frames (see *Art. 102*) which are structural parts of the hull.

29. Tons per inch immersion. The areas of two waterline planes separated vertically by a distance of one inch will be practically equal. The volume in cubic feet of such a layer may

be obtained by multiplying the area of the waterline in square feet by one twelfth since one inch is one twelfth of a foot. The weight of such a volume of salt water in tons is $1/35$ th of this volume since 35 cubic feet of sea water weigh 1 ton. Therefore the gain in displacement when a ship sinks parallel to her original waterline a distance of one inch or the weight which must be added to the ship to produce an increase of draft of one inch is numerically equal to the area of the waterline divided by twelve times thirty-five. This value is known as the "tons per inch immersion" and denoted by T .

$$T = \frac{A_{w1}}{12 \times 35} = \frac{A_{w1}}{420}$$

30. Change of draft when changing from salt to fresh water.

The displacement of the ship in water of two different densities 35 and 36 cu. ft. per ton is plotted. Salt water has a density of 1.024 and weighs 64 lbs. per cu. ft. and there are therefore exactly 35 cu. ft. per ton; fresh water weighs 62.5 lbs. per cu. ft. and there are therefore 35.84 cu. ft. per ton. The displacement in brackish water is obtained as indicated in attached examples.

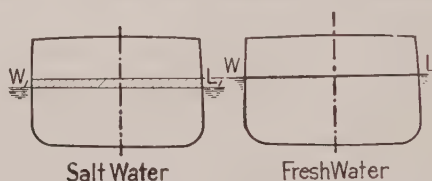


FIG. 6.—DIFFERENCE OF DRAFT IN FRESH AND SALT WATER.

The ship of Plate II draws 21 ft. forward and aft; density of water by hydrometer is 1.010. What is her displacement?

Displacement in salt water density 1.024 curve 1 = 10,600 tons

Therefore displacement in water of density 1.010 =

$$\frac{1.010}{1.024} \times 10,600 = 10,455 \text{ tons.}$$

The ship of Plate II in the Pacific Ocean draws 19 ft. forward and aft. She is to go up the Columbia River to Portland. To do so she must cross a bar in the river where the depth of water is 20 ft. Can she make it without discharging any weight?

$$W = 9400 \text{ tons}$$

Draft in fresh water for 9400 tons displacement is 19 ft. 5½ in. Therefore ship can clear by 6½ in.

If the displacement curves of a ship are not available the difference in draft between fresh and salt water may be computed by the following formula:

$$d = \frac{W \left(\frac{35.84}{\delta} - 35 \right)}{35 T}$$

where d is this difference in draft in **inches**

W = weight of ship in tons

δ = density of water

T = tons per inch immersion

A ship when fully laden, displacement 12,000 tons draws 24 ft. in salt water. Tons per inch at this draft is 50. To what draft should she be loaded at New Orleans? Density of Mississippi River is 1.006.

$$d = \frac{12,000 \left(\frac{35.84}{1.006} - 35 \right)}{35 \times 50} = 4.22 \text{ inches}$$

Ship may be loaded to 24 ft. 4¼ in.

Problems

1. You are required to completely renew the insulation on a bulkhead whose half ordinates are 0.3, 6.0, 8.0, 10.0, 11.0, 11.8, 12.3, 12.7 and 12.9 feet respectively, and common interval 2 feet. How many square feet of cork slabs would be required to do this job, allowing 10 per cent for waste?

Ans. 353.8 Simpson's First Rule; 350.7 Trapezoidal Rule.

2. You are required to renew completely the linoleum on a deck whose half ordinates are 0.2, 5.9, 10.5, 13.1, 14.2, 14.5, 14.5, 14.0, 12.6, 9.8 and 0.2 feet respectively and common interval 15 feet. How many square feet of linoleum will be required to do this job, allowing 10 per cent for waste?

Ans. 3702.2 Simpson's First Rule; 3643.3 Trapezoidal Rule.

3. You are required to red lead a bulkhead whose half ordinates are 0.0, 2.75, 5.50, 8.20, 10.60, 13.20 feet respectively, and

common interval 2.5 feet. How many pounds of red lead would be required? One pound of red lead will cover 6 square feet of surface.

Ans. 28.04.

4. You are required to paint an engine room bulkhead whose semi-ordinates are 26.6, 26.8, 26.8, 26.4, 25.4, 23.4 and 18.5 feet respectively, the ordinates being 3 feet apart. How many gallons of paint would be required? One gallon of paint will cover 50 square yards of surface.

Ans. 2.02.

5. You are required to renew completely a wood deck whose semi-ordinates are 0, 5.0, 9.6, 12.6, 14.4, 14.5, 14.4, 13.5, 11.3, 6.5 and 0.5 feet respectively, with a common interval of 14.5 feet. How many square feet of decking will be required, allowing 25 per cent for waste?

Ans. 3947.9.

6. You are required to renew completely the linoleum on a section of deck having ordinates at a common distance apart of 2.5 feet, the length of the ordinates being 3.50, 4.70, 5.60, 6.30, 7.00, 7.50 and 7.90 feet. How many square feet of linoleum will be required, allowing ten per cent for waste?

Ans. 102.5 Simpson's Rules; 101.9 Trapezoidal Rule.

7. The half breadths of frame number 135 of the S. S. *California* are 0.8, 2.0, 4.9, 9.1, 13.7, 17.9, 21.3, 23.6, 25.1. The distance between ordinates is 4 feet. Find the area of a section of the ship at this point by Simpson's First Rule.

Ans. 843.

8. The half breadths of the midship section of a ship are 0.6, 24.7, 26.4, 26.9, 27.2, 27.3, 27.4, 27.5. The distance between waterlines is 2 feet. Find the area by the trapezoidal rule. What is the coefficient of fineness of the midship section?

Ans. Area 696. Coefficient 0.904.

9. The sectional areas at alternate frames of a reserve feed water tank are 19.4, 18.5, 17.2, 15.6, 13.6, 10.9 and 6.5 sq. ft. respectively. The frame space is 2 feet. Find the volume by Simpson's Rules. Find the capacity in gallons. 1 cu. ft. of water = 7.48 gallons.

Ans. 2668 gal.

10. The areas of sections of a fuel oil tank on the S. S. *Mololo* measured at every fourth frame are 135, 170, 186, 200 and 212

sq. ft. respectively. The frame space is 4 ft. Find the volume, using the trapezoidal rule. Allowing 7.48 gallons per cubic foot, how many gallons will the tank hold when filled to 95% of its capacity?

Ans. 83,000.

11. The areas of stations on the U. S. S. *Sacramento* in sq. ft. are 0, 31, 66, 111, 163, 221, 281, 338, 385, 420, 428, 416, 387, 342, 288, 218, 170, 113, 61, 22 and 0. The distance between stations is 11.6 ft. Find the volume by the trapezoidal rule. What is the displacement in salt water?

Ans. 51,747.6 cu. ft.; 1478 tons.

12. A fuel oil tank has sectional areas of 19.4, 18.5, 17.2, 15.6, 13.6, 10.9 and 6.5 square feet respectively, the distance between sections being 12.5 feet. How many gallons of fuel oil will it hold? One gallon measures 231 cubic inches.

Ans. 8337 Simpson's First Rule; 8315 Simpson's Second Rule; 8302 Trapezoidal Rule.

13. Half breadths of a bulkhead are 0.4, 7.2, 10.8, 12.8, 13.8, 14.1, 14.2, 14.1, 14.0, 13.9, 13.8 and 13.6. The distance between waterlines is 2 ft. What is the height of the center of gravity of the bulkhead above the base line? Use trapezoidal rule.

Ans. 12.18 ft.

14. The 12-foot waterline of the U. S. S. *Cincinnati* has the following half breadths: 0, 4.5, 9.0, 13.3, 17.1, 20.4, 23.1, 25.1, 26.5, 27.2, 27.4, 27.3, 27.2, 26.8, 25.8, 24.1, 21.4, 17.6, 12.6, 6.6, and 0. The distance between stations is 27.5 feet. What is the distance of the center of gravity from the midship section? Use trapezoidal rule.

Ans. 10.0 ft. aft.

15. Half breadths of the designer's waterline (molded) of the S. S. *California* are 0.1, 6.5, 15.1, 23.8, 31.8, 38.2, 42.5, 45.4, 46.9, 47.6, 47.7, 47.6, 47.4, 46.8, 45.5, 43.0, 39.0, 32.9, 24.4, 13.3 and 0. The distance between stations is 30 feet. What is the distance of the center of flotation from the dead flat? Use trapezoidal rule.

Ans. 12.36 ft. aft.

16. The after engine room bulkhead of a destroyer has the following half breadths: 0.4, 6.3, 10.0, 12.1, 13.4, 14.0, 14.2, 14.1, 14.0, 13.8 and 13.6. The distance between waterlines is 2 feet.

Find the distance of the center of gravity of half of the bulkhead from the centerline plane. Use Simpson's First Rule.

Ans. 6.45 ft.

17. Using the values of half breadths of the designer's waterline on the S. S. *California* given in problem 15. Find the distance of the center of gravity of half of the designer's waterline from the centerline plane. Use trapezoidal rule.

Ans. 20.4 ft.

18. Using the values of half breadths of the 12-foot waterline of the U. S. S. *Cincinnati* given in problem 14, find the distance of the center of gravity of half of this waterline from the centerline plane. Use trapezoidal rule.

Ans. 11.41 ft.

19. The load waterline of a ship has semi-ordinates of 0.1, 10.3, 20.1, 27.5, 32.2, 34.0, 33.9, 31.8, 27.7, 20.7 and 9.5 feet respectively at intervals of 40 feet. Find the area and the distance of the c. g. from the middle ordinate.

Ans. Area 19,589 sq. ft.; c. g. 16.16 ft. aft No. 6; Simpson's First Rule. 19,440 sq. ft.; c. g. 16.24 ft. aft No. 6 Trapezoidal Rule.

20. The semi-ordinates of a waterline are 4.1, 9.1, 13.3, 16.8, 19.5, 21.6, 23.2, 24.4, 25.1, 25.4, 25.5, 25.2, 24.3, 22.8, 20.7, 17.7, 14.3, 10.4, 6.1, 2.2 and 1.1 feet. Common interval is 18 feet. Where would you place a boat cradle on this vessel so as not to cause a list or change of trim? (No list or change of trim will occur if added weights are placed over the c. g. of the waterline plane.)

Ans. 12.95 ft. forward No. 11; Simpson's First Rule.

12.74 ft. forward No. 11; Trapezoidal Rule.

21. An area bounded by a curve and a straight line is divided by ordinates 4 feet apart, of the following lengths: 0, 12.5, 14.3, 15.1, 15.5, 15.4, 14.8, 14.0 and 0 feet respectively. Find the position of the c. g. relative to the base.

Ans. 7.2 ft. Simpson's First Rule; 7.3 ft. Trapezoidal Rule.

22. The sectional areas of a bunker are 142, 170, 181, 176 and 165 square feet respectively, and the distance between sections is 10 feet. Find the longitudinal position of the center of gravity.

Ans. 0.34 ft. aft No. 3, Simpson's First Rule.

0.44 ft. aft No. 3, Trapezoidal Rule.

23. Find the volume of displacement and the location of the center of buoyancy of a 40-foot motor boat having breaths as follows:

Sections No.	1	2	3	4	5
Base Line	0.2	0.2	0.2	0.2	0.2
2' W.L.	0.2	2.0	7.6	2.6	0.3
4' W.L.	0.2	5.3	10.5	6.5	0.3
6' W.L.	0.2	7.4	11.0	9.3	2.0

Use trapezoidal rule.

Ans. 998 cu. ft.; 0.783 ft. aft No. 3; 4.05 ft. above base line.

24. Find the location of the center of gravity of half of the forward cargo hold of the S. S. *Bridge* which has ordinates as follows:

Section No.	1	2	3	4	5
0 level line	4.8	9.0	12.7	14.2	14.4
5' level line	9.8	15.0	18.7	19.9	20.1
10' level line	12.7	17.6	20.5	21.5	21.6
15' level line	14.5	19.0	21.2	21.7	21.8
20' level line	15.7	19.6	21.3	21.7	21.8

The distance between sections is 15 ft. Use trapezoidal rule. Solve by finding area and location of center of gravity of each section and then the volume and center of gravity of the compartment as explained in *Art. 26*.

Ans. 2.565 ft. aft No. 3; 10.82 ft. above 0 level line; 9.44 ft. from centerline.

25. Refer to Plate II and assuming draft forward 20'6" and draft aft 22'0". What is displacement (salt water)? The vessel now moves into a fresh water harbor. What will be her extreme draft? (Assume same trim as in salt water.) While at dock she takes on fuel oil which increases her mean draft to 22 ft. How much fuel oil did she receive? What will be her mean draft when she steams into salt water?

26. Refer to Plate II and assuming mean draft 20'6"; trim by stern, 3'0", what is displacement (salt water)? What will be the extreme draft when the vessel passes into a fresh water

harbor? (Assume same trim as in salt water.) Cargo is now unloaded from the vessel until her mean draft is reduced by 6". How many tons of cargo were removed? What will be her mean draft when she returns to salt water?

27. Refer to Plate II. The draft forward is 22'0" and that aft is 23'0". What is the exact displacement in salt water? What is vertical position of C. B. above keel? What is longitudinal position of C. B. relative to station No. 10? What is area of waterline? What is tons per inch immersion? What is area of wetted surface? What will be mean draft if vessel passes into fresh water?

28. The draft of the vessel of Plate II when fully loaded is 24 feet forward and 26 feet aft. How many gallons of underwater paint will you need to give her one coat of paint over the underwater body? (Use Plate II. One gallon of paint will cover 30 square yards of surface.)

Ans. 45.3.

29. The half breadths of the 10 ft. waterline of the U. S. S. *Converse* are 0.1, 2.4, 4.8, 7.2, 9.3, 11.3, 12.9, 14.1, 14.9, 15.3, 15.4, 15.3, 15.0, 14.6, 14.0, 13.1, 11.7, 9.8, 7.3, 4.0, 0.3. The distance between ordinates is 15.5 feet. Find the area by the trapezoidal rule. What is the tons per inch immersion?

Ans. Area 6593.7; $T = 15.7$.

30. The tons per inch immersion of the U. S. S. *Pennsylvania* is 101.5. What is the area of the designer's waterline?

Ans. 42,630.

31. The area of a waterline is 9,648 square feet. Find the tons per inch immersion. If 200 tons of fuel are taken aboard what will be the increase of draft?

Ans. $T = 22.97$; 8.7 inches increase in draft.

32. The tons per inch of a ship at waterlines 4 feet apart, commencing at the D. W. L. are 45.3, 43.7, 41.5, 38.5, 34.3, and 0 respectively. Find the position of the C. B. below the D. W. L.

Ans. 8.4 feet.

33. The U. S. S. *Raleigh* lying at League Island Navy Yard (fresh water) was drawing 14 feet 9 inches, corresponding displacement 7,800 tons. Before departure 15,000 gallons of shore water, 12,000 lbs. of fresh meat, 40,000 lbs. of fresh vegetables and 25 tons of ammunition were taken on board. The tons per inch immersion is 50.8 and fresh water weighs 8.35 lbs. per gallon.

What was her draft on reaching Delaware Breakwater (salt water)?

Ans. 14 ft. 6.61 in.

34. The cruiser *Seattle* is ordered to proceed to Portland, Oregon. Her mean draft taken in the Pacific just before entering the Columbia River is 28'4" corresponding to a displacement of 14,800 tons. Tons per inch immersion (both salt and fresh water) is 75. Portland is 120 miles up the river and to get there it is necessary to cross a shoal spot 20 miles below the city where there is only 28'3" of water. Between the entrance to the Columbia River and this shoal spot, 105 tons of coal, stores, etc., are consumed. Prove that the *Seattle* can or cannot pass the shoal and by what amount.

Ans. Can not pass by 5.2".

35. The mean draft of the S. S. *Mololo* before fueling is 28 ft. After fueling her mean draft is 29 ft. 8 inches. If the tons per inch immersion for the range of drafts given has a mean value of 101.5 and the oil has a density of 300 gallons per ton, how many gallons of fuel did she take?

Ans. 609,000.

36. The carpenter on the U. S. S. *Milwaukee* took the draft before getting under way in the North River (fresh water). After she got into Long Island Sound (salt water) she took 65,000 gallons of fuel oil and the carpenter found that after fueling her draft was the same at it was before leaving her anchorage. What was her displacement after fueling?

Ans. 7,800 tons.

CHAPTER II

STABILITY

SECTION A—EQUILIBRIUM OF FLOATING BODIES

31. **Equilibrium and stability.** The tendency of a body to right itself when moved from its normal position of rest is called its **statical stability**. To take a familiar example, if an ordinary chair is tilted a small amount, it tends to return to its normal position with all four legs on the floor. Such a body possesses statical stability. Statical stability is measured in terms of either righting moment or righting arm (righting moment divided by weight). To change the position of a body possessing statical stability, in the example, to tilt the chair, force must be exerted on it and a certain amount of work done. **The work done in moving a body from its normal position to another position is the dynamical stability of the body.**

It is common experience that if we tilt our chair a small amount, it will return to the normal position or upright when released. Within that range the chair or any similar body is said to be in **stable equilibrium**. Work must be done upon it to move it further from its normal position and as soon as the working force is removed it returns to its normal position. If we continue tilting the chair, a point is reached when the chair is balanced on two legs. Further tilting will put it in the condition that it must be restrained from falling on its back. It has lost all tendency to return to the upright or normal position. **Such a body is said to be in unstable equilibrium.**

A body is said to be in **neutral equilibrium** when it is in equilibrium regardless of its position. A homogeneous sphere on a plane surface is a good example of this condition of equilibrium.

In the previous chapter the methods employed to compute areas and volumes have been explained. In particular we have seen how

the displacement and the location of the center of buoyancy is determined. In this chapter we shall discuss the fundamental considerations on which the computations for the stability of ships are based and the effect of various conditions on stability.

32. Conditions required for equilibrium. If a body is in equilibrium it is acted upon by no unbalanced forces. That is, the sum of the horizontal forces is equal to zero; the sum of the vertical forces is equal to zero; the sum of the moments of all the forces about any axis is equal to zero.

A ship floating at rest in the water is in equilibrium and must therefore fulfill the three conditions stated. The first requires no comment. The second translated to ship terms means that the force of buoyancy acting vertically upward through the center of buoyancy equals the weight of the ship acting vertically downward through the center of gravity of the ship. The third condition is fulfilled only if the forces of weight and buoyancy act in the same vertical line, i.e., the center of gravity of a ship floating at rest in the water is in the same vertical line as the center of buoyancy.

33. Effect of the position of the metacenter on equilibrium. In *Art. 15* the metacenter was defined as the point in which verticals through the centers of buoyancy meet when the inclination is small. This point therefore lies on the vertical passing through the center of gravity of the ship and the center of buoyancy when the ship is erect. Therefore it may be above the center of gravity of the ship, coincident with it or below it. Fig. 7 represents the first condition. In this case when the ship is given an inclination a couple or moment equal to the weight of the ship multiplied by GZ is set up to bring the ship erect. In the second case, shown in Fig. 8, the ship is in equilibrium in the inclined condition just as it is in the erect condition. In the third case, see Fig. 9, the couple $W \times GZ$ is an upsetting couple, i.e., instead of righting the ship it tends to turn her over. It follows therefore, that **if a ship possesses statical stability the metacenter is above the center of gravity of the ship.**

34. Conditions requisite for equilibrium in an inclined position. When a ship whose metacenters (transverse and

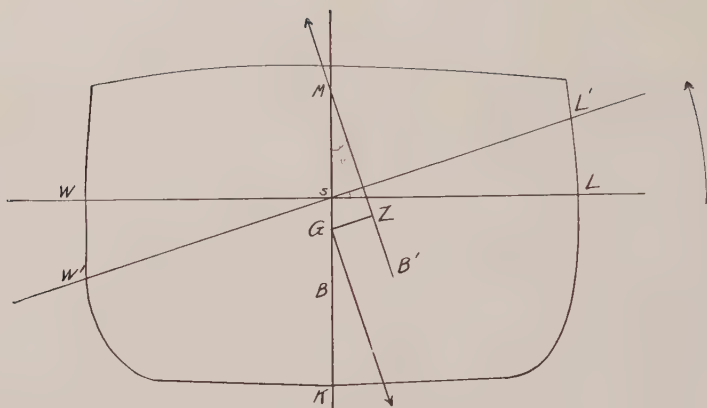


FIG. 7.—SHIP IN STABLE EQUILIBRIUM.

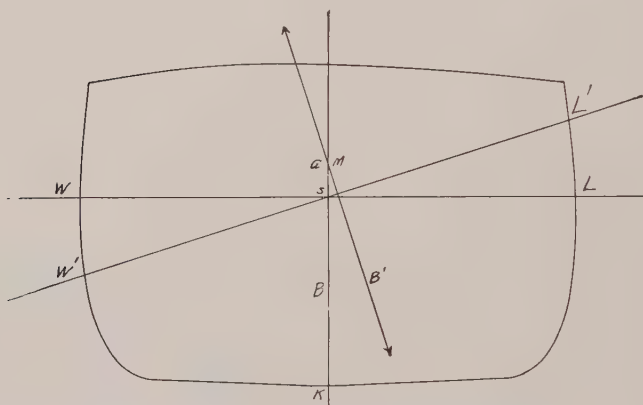


FIG. 8.—SHIP IN NEUTRAL EQUILIBRIUM.

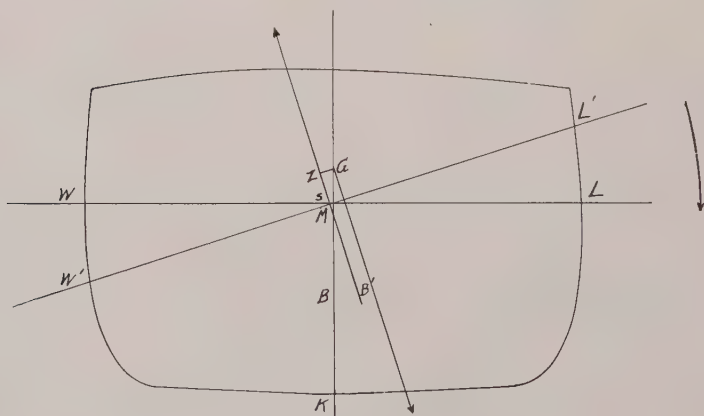


FIG. 9.—SHIP IN UNSTABLE EQUILIBRIUM.

longitudinal) are above her center of gravity is given a small inclination (transverse or longitudinal) the righting moment is $W \times GZ$ as shown in Figs. 7 and 10.

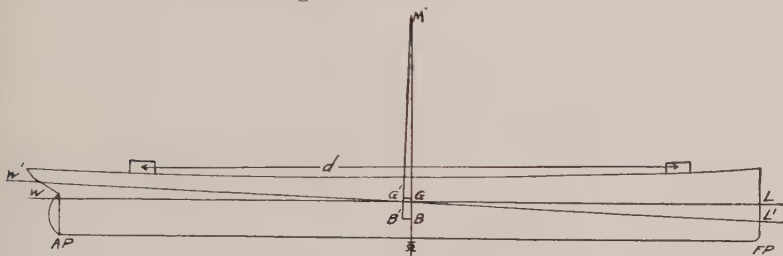


FIG. 10.—SHIP IN STABLE EQUILIBRIUM (LONGITUDINAL INCLINATION).

But $GZ = GM \sin \theta$ for transverse inclination.

And $GZ = GM' \sin \theta$ for longitudinal inclination.

Therefore in an inclined position the righting moment is $W \times GM \sin \theta$ for transverse inclinations and $W \times GM' \sin \theta$ for longitudinal inclinations.

If the ship is in equilibrium in the inclined position the moment producing the inclination is equal to the righting moment, since the sum of the moments about any axis is equal to zero.

The commonest way of giving a ship an inclination is by moving a weight. There is no difference in nature between transverse inclinations and longitudinal inclinations. The mathematical discussion for a transverse inclination follows. The discussion for a longitudinal inclination differs only in that GM' , the **longitudinal metacentric height**, should be substituted for GM , the **transverse metacentric height**.

Referring to Fig. 11:

Let W = displacement of ship.

w = weight moved.

d = distance weight w is moved.

θ = angle of inclination when w has been moved distance d .

B' = center of buoyancy when ship is inclined.

When weight w is moved a horizontal movement of the center of gravity of the ship is produced. When equilibrium in the inclined position is reached the new center of gravity of the ship

lies in the line $B'M$, since for equilibrium in the case of a floating body, the forces of weight and buoyancy must act in the same vertical line.

$$\text{From the above } W \times GZ = w \times d \cos \theta$$

$$GZ = GM \sin \theta$$

$$\therefore W \times GM \sin \theta = w \times d \cos \theta$$

The above equation contains five quantities; given any four the fifth may be computed.

For a longitudinal inclination the formula is

$$W \times GM' \sin \theta = w \times d \cos \theta$$

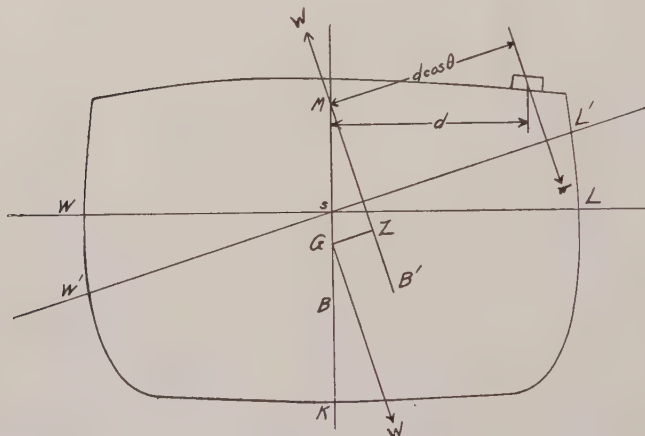


FIG. 11.—SHIP IN EQUILIBRIUM IN INCLINED POSITION.

SECTION B—COMPUTATION OF METACENTRIC RADIUS, METACENTRIC HEIGHT AND MOMENT TO CHANGE TRIM

35. Computation of metacentric radius. From the foregoing discussion, it is clear that for a comprehension of the stability characteristics of a ship we must know the location of her transverse and longitudinal metacenters and center of gravity. The methods of computing the locations of these points are given in this section.

(A) in Fig. 12 shows the cross section of a ship and (B) the waterline at which she is floating. If the ship is heeled over to a small angle of inclination so that she now floats at the waterline $W'L'$ instead of WL the location of the C. B. changes from B to B' as explained in *Art. 15* in the definition of metacenter.

Let r = half breadth

$d\theta$ = angle of inclination

n = center of gravity of triangle $L'OL$

dx = increment of length (L)

V = volume of displacement

Area of triangle $LOL = \frac{1}{2}r \times rd\theta$

on $= \frac{2}{3}r$, since $d\theta$ is small.

Moment of area of triangle $L'OL$ about longitudinal centerline

$$= \frac{1}{2}r \times rd\theta \times \text{on}$$

$$= \frac{1}{2}r \times rd\theta \times \frac{2}{3}r.$$

Moment of wedge having triangle $L'OL$ for its section and of

thickness $dx = \frac{1}{2}r \times rd\theta \times \frac{2}{3}r \times dx.$

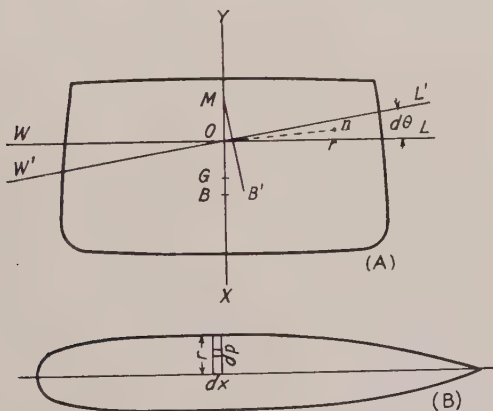


FIG. 12.—METACENTRIC RADIUS.

Moment of wedge for entire length of ship $= \int_0^L \frac{1}{2}r \times rd\theta \times \frac{2}{3}r \times dx$. Since the weight of the ship is unchanged, its displacement is unchanged. That is, the volume of the **emerged** wedge WOW' equals the volume of the **immersed** wedge $L'OL$, and since their arms are equal, the moments of these wedges will be equal. The

action of the emerged wedge due to the fact that its weight is no longer water-borne is to produce in the case under discussion counter-clockwise rotation of the ship, i.e. to right her. Similarly the action of the added buoyancy of the immersed wedge $L'OL$ is to produce counter-clockwise rotation of the ship because we have a volume immersed which is normally above water. Thus the moments of the two wedges are equal and act to produce rotation in the same direction.

$$\begin{aligned}\therefore \text{the total change of moment} &= \int_0^L 2 \times \frac{1}{2}r \times r d\theta \times \frac{2}{3}r \times dx \\ &= \int_0^L \frac{2}{3}r^3 d\theta \, dx\end{aligned}$$

But by mechanics the total change of moment equals the total volume times its shift of center of gravity equals $V \times BB'$. And $BB' = BM \sin d\theta = BM d\theta$, since $d\theta$ is small.

$$\therefore V \times BM \cdot d\theta = d\theta \int_0^L \frac{2}{3}r^3 \, dx$$

$$\text{or } BM = \frac{\int_0^L \frac{2}{3}r^3 \, dx}{V}$$

But by mechanics $\int_0^L \frac{2}{3}r^3 \, dx$ is the expression for the moment of inertia of the waterline about the longitudinal centerline. If we designate this value by I , we have the usual equation for locating M .

$$BM = \frac{I}{V}$$

Similarly it may be shown that

$$BM' = \frac{I'}{V}$$

where M' is the longitudinal metacenter and I' is the moment of inertia of the waterline about a transverse axis through the center of flotation. Since the moment of inertia varies as the cube of the dimension perpendicular to the reference axis and since a ship is much longer than wide, I' is much greater than I and consequently BM' is much greater than BM .

The computation of BM requires the determination of two things:

- (a) The moment of inertia of the waterline about the longitudinal centerline.
- (b) The volume of displacement.

The method of computing (b) was given in Chapter I. The method of computing (a) is to apply one of the rules of mensuration to the cube of the ordinates.

Example:—The half ordinates, spaced 16.6 feet apart, of a waterline are 0.2, 2.3, 6.4, 9.9, 12.3, 13.5, 13.8, 13.7, 12.8, 10.6, 6.4, 1.9, 0.2. If the displacement up to this waterline is 220 tons, find BM by Simpson's First Rule.

Half- Ordinate	Cube of Half Ordinate	Multiplier	Function of Cubes
0.2	0.0	1	0.0
2.3	12.1	4	48.4
6.4	262.1	2	524.2
9.9	970.3	4	3881.2
12.3	1860.8	2	3720.6
13.5	2460.3	4	9841.2
13.8	2628.0	2	5256.0
13.7	2571.3	4	10285.2
12.8	2097.1	2	4194.2
10.6	1191.0	4	4764.0
6.4	262.1	2	524.2
1.9	6.8	4	27.2
0.2	0.0	1	0.0
Sum	—————	—————	43066.4

$$I = \frac{1}{3} \times 16.6 \times \frac{2}{3} \times 43,066.4$$

We multiply by one third the common interval for Simpson's Rule and two thirds the sum of the functions of cubes for the moment of inertia.

$$\begin{aligned}
 V &= 220 \times 35 \\
 BM &= \frac{\frac{1}{3} \times 16.6 \times \frac{2}{3} \times 43,066.4}{220 \times 35} \\
 &= 20.6 \text{ ft.}
 \end{aligned}$$

We have seen in Chapter I how to determine the location of B. The formulæ for BM and BM' enable us to locate M and M' after the location of B has been computed. The locations of M and M' for various drafts are plotted, see curves 10 and 11 of Plate II.

36. Computation of metacentric height; Inclining experiment. Owing to the complexity of the structure of a ship, the fact that practically none of its structural members are straight lines or curves of simple form, it is an exceedingly long and tedious calculation to determine its center of gravity by computation. There are in fact so many indeterminate weights such as paint, rivets, cement, liners, butt laps, etc., that the calculated center of gravity is seldom exact and must be checked by the inclining experiment. In the early stages of design, the location of this point is estimated from previous ships. It is accurately determined when the ship is practically completed by the inclining experiment which is the only reliable and practical means for determining the location of the center of gravity of the ship.

The location of M was determined by computing BM, the vertical distance of M above B when the ship is erect. Similarly to locate G we obtain GM by the inclining experiment. We cannot plot a curve of location of G against draft because for any given draft there are an infinite number of positions for G since the location of G depends not upon the amount of the ship's weight but on its distribution. In other words the locations of M and M' are functions of the geometrical properties of the ship; the location of G is a function **only of the loading**.

The theory of the inclining experiment is that we incline the ship by a moment of known amount and since the ship assumes a position of equilibrium in the inclined position, the righting moment must equal the inclining moment as explained in *Art. 34*. The preparations for the experiment are of great importance, the actual performance is simple and takes little time. The principal requirements which must obtain when the ship is inclined are:

(a) The ship must be floating freely; care should be taken to see that she is not lying against piling or resting in mud.

(b) There must be no free liquid, i.e. no water or fuel oil hav-

ing a free surface; all boilers and tanks must be either full or empty; bilges should be dry.

(c) All lines should be slacked except head line. Best results are obtained if there is no wind or water current.

(d) All weights on board must be secured so that they will not shift. As far as practicable miscellaneous dunnage should be put ashore. Just before the experiment a check should be made on the contents of all storerooms.

(e) If possible the crew should be sent ashore or if they remain on board kept on the centerline of the ship.

A favorite place to perform this experiment is in dry dock, dock flooded but caisson in position. The inclining weight or weights (frequently the inclining weight is made up in two or three lots and distributed uniformly along the ship's length) are placed on the centerline. Plumb bobs are rigged down hatches forward and aft and their positions on transverse battens noted. The weights are then shifted a predetermined amount to one side. The ship heels over and the transverse battens move under the plumb lines. The amount of this movement divided by the length of the plumb lines gives $\tan \theta$. The weights are then shifted across the deck and readings of the apparent movement of the plumb lines again taken. The weights are then brought back to the centerline and the zero reading checked.

During the experiment the draft of the ship forward and aft and the density of the water by hydrometer is measured. With this information we obtain from the displacement curves the displacement of the ship which is numerically equal to its weight. The inclining weight is carefully weighed and the distance it is moved measured and marked.

Applying our data to the fundamental equation for equilibrium in the inclined condition deduced in *Art. 34*:

$$W \times GM \sin \theta = w \times d \cos \theta$$

we find that we have everything except GM which may therefore be computed from this equation thereby determining the location of the center of gravity of the ship, since we know that M is above G .

The ship of Plate II is inclined by moving a weight of 35 tons

a distance of 22 ft. from the centerline. A 16 ft. plumb bob is deflected 10 inches. The ship draws 13 ft. forward and 18 ft. 6 in. aft. Density of water 1.025. What is the height of the center of gravity above the base?

Mean draft = 15 ft. 9 in.

W (approx., curve 1) = 7,500 tons

Correction for trim = $5.5 \times \frac{570}{200} = 16$ tons

Displacement in salt water = 7516 tons

True W $\frac{1.025}{1.024} \times 7516 = 7523$ tons

$W \times GM \sin \theta = w \times d \cos \theta$

or $GM = \frac{w \times d}{W} \cot \theta = \frac{35 \times 22}{7523} \times \frac{192}{10} = 1.97$ ft.

From curve 10, height of transverse metacenter above base line, KM = 27 ft. 10 in. = 27.83 ft.

KG = KM - GM = 27.83 - 1.97 = 25.86 ft.

The method given above for computing the moment of statical stability is known as the metacentric method. It is applicable only for inclinations which do not produce a change in the location of M. It has been found by experience that this condition is fulfilled if the inclination does not exceed 10° .

Values of GM for merchant ships in light condition vary from zero (sometimes negative) to one or two feet; GM when loaded depends upon the class of cargo and method of disposing it in the holds.

37. Computation of moment to change trim. The moment to change trim one inch is the moment in foot-tons which will produce such a longitudinal inclination that the change of trim is one inch. Since longitudinal inclinations are always small, usually less than 1° , they are expressed in change of trim or drafts rather than in degrees and minutes. When the change of trim is one inch, the longitudinal inclination is the angle whose tangent is $\frac{1}{12} \div L$, i.e. $\frac{1}{12L}$, since 1 inch = $\frac{1}{12}$ ft. The fundamental equation for equilibrium as deduced in *Art. 34*,

$W \times GM' \tan \theta = w \times d$ reduces to

$w \times d = W \times GM' \times \frac{1}{12 L} = \frac{W \times GM'}{12 L} = C$, where C is the moment to change trim one inch.

For any draft the probable variation in the location of G is small compared to the value of GM' . No appreciable error will therefore occur if for each draft we assume a mean value of GM' and compute the moment to change trim one inch at that draft with the assumed value of GM' . This is done and the values obtained plotted on the displacement scale, see curve 12.

Compute the moment to change trim one inch for the ship of Plate II when her draft forward and aft is 20 ft. and $GM' = BM'$. Check by curve 12.

$$W = 10,000 \text{ tons}$$

$$BM' = GM' = \frac{3250}{5} = 650 \text{ ft.}$$

$$C = \frac{10,000 \times 650}{12 \times 460} = 1177 \text{ ft. tons}$$

$$\text{By curve 12, } C = \frac{5880}{5} = 1176 \text{ ft. tons.}$$

SECTION C—CONDITIONS AND OCCURRENCES AFFECTING STABILITY

38. Adding, removing and moving weights. The addition or removal of a weight affects both the displacement and stability of the ship; the movement of a weight on board affects only the stability, the displacement remaining unchanged. The movement of a weight causes the center of gravity of the ship to change position. This change of position of G may have three components, vertical, transverse and longitudinal. Each of these components has a distinct effect upon the ship. The vertical component produces a change in GM since G moves, but M remains fixed since its location is a function of the volume of displacement. The transverse component produces a transverse inclination; the longi-

tudinal component produces a longitudinal inclination or change of trim.

The ship of Plate II in salt water draws 24 ft. forward and 23 ft. aft and has a list of 3° to port. From an inclining experiment the center of gravity of the ship is known to be 22 feet above the base line. What will be the condition of the ship if 100 tons of flour is placed in #4 between decks with the center of gravity of this flour 35 feet above the base line, 20 feet to starboard of the centerline and 180 feet aft of the midship section?

$$\text{Draft forward} = 24 \text{ ft. } 0 \text{ in.}$$

$$\text{aft} = 23 \text{ ft. } 0 \text{ in.}$$

$$\text{mean} = 23 \text{ ft. } 6 \text{ in.}$$

For 23 ft. 6 in. mean draft, the tons per inch immersion (curve 7) is 50.4.

$$\text{Increased draft due to added weight} = \frac{100}{50.4} = 2 \text{ inches.}$$

Increase in vertical moment of ship about the base line $= 100 \times 35 = 3500$ ft. tons.

$$\text{From curve 1 approximate } W = 12,100 \text{ tons}$$

$$\text{Correction from curve 13} = (-) 14 \text{ tons}$$

$$\therefore W = 12,086 \text{ tons}$$

$$\text{Rise of } G = \text{Reduction of } GM = \frac{3,500}{12,186} = 0.29 \text{ feet.}$$

Call new center of gravity G' and point vertically below it at base line K ; then $KG' = 22.0 + 0.29 = 22.29$ ft.

$$\text{By curve 10, } KM = 25.50 \text{ ft.}$$

$$\therefore G'M = 3.21 \text{ ft.}$$

The longitudinal metacentric height GM' has been reduced the same amount as GM , 0.29 ft., but this is such a small part of it that this reduction in GM' can be neglected.

The trimming moment is $100 \times 180 = 18,000$ ft. tons.

By curve 12 the moment to change trim one inch $= 1,260$ ft. tons.

$$\therefore \text{The change of trim} = \frac{18,000}{1,260} = 14.29 \text{ inches.}$$

Summarizing changes in drafts.

Drafts before adding weight	forward 24 ft. 0 in.	aft 23 ft. 0 in.
Sinkage	+ 2 in.	+ 2 in.
Trim	- 7 in.	+ 7 in.
Drafts after adding weight	23 ft. 7 in.	23 ft. 9 in.

The transverse inclination due to the addition of this weight may be obtained from the fundamental formula for stability in an inclined position, $W \times GM \sin \theta = w \times d \cos \theta$

$$\tan \theta = \frac{w \times d}{W \times GM} = \frac{100 \times 20}{12,186 \times 3.21} = 0.0512.$$

$\therefore \theta = 2^\circ 56'$ to starboard.

But the ship was initially inclined 3° to port.

$\therefore$ her inclination after the addition of the weight is practically zero.

From the discussion given it is seen that there are three distinct effects produced by adding, taking away or moving a weight: first, a change of trim; second, a transverse inclination; third, a change in the initial stability. Due to the serious consequences which may result from indiscriminate movement of weights in dry dock, such movement except by express permission of the docking authorities is forbidden. It is desirable that no change of weights should be made in dry dock, but it is not always possible to avoid this. In such cases the shift of weights should be such that the resultant trimming and inclining moments are zero **and that there is no reduction in GM**. In all cases no actual movement of the weights should be made until the official responsible for the safety of the ship in dry dock has been consulted and his approval of the proposed changes obtained. Failure to give adequate consideration to the effects produced by shift of weights has caused ships to be damaged seriously during undocking.

A shift of weights on a water-borne ship is not so likely to produce serious results because the effect on the ship becomes apparent during the shift. Nevertheless the operating personnel should keep in mind constantly that every shift of weights produces these three results and if for any reason the ship is in a tender condition the ill-considered or accidental movement of a large weight such as shifting of the cargo may cause her loss.

39. Grounding. Grounding is primarily a special case of the movement of weights as discussed in the preceding article. It is important not only due to the accidental groundings of ships in service but due to the fact that ships are periodically docked for examination, painting and repair, and docking is a special case of grounding. As such the stability of the ship during docking must be adequately provided for.

When a ship grounds she is no longer a floating body. Part of her weight is taken by the pressure on the ground. In air the major portion of the weight of articles resting on the floor is taken by the upward thrust of the floor, only a small part being taken by the buoyant force of the air. In the usual cases of grounding the buoyant force of the water and the upward thrust at the bottom

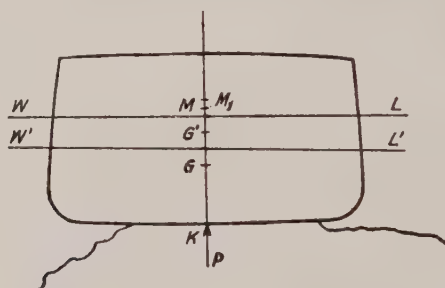


FIG. 13.—STABILITY WHEN GROUNDED.

both have to be considered. Part of the weight of a grounded ship is neutralized at the point of contact. The effect on the ship as a floating body is just the same as if this much weight were removed from her and she were a floating body of different displacement and distribution of weights. The removal of a weight at the keel **does not reduce the vertical moment** of the weight of the ship at all, since its arm is zero. The displacement of the ship is reduced by the amount of the pressure. **Therefore the result of grounding is equivalent to raising the center of gravity of the ship.** The location of the transverse metacenter will change due to change of location of the center of buoyancy, the change in the moment of inertia of the waterline and the change in the volume of displacement. In other words M may go up or down; G goes up; if G reaches M any force such as the pressure of the wind on the ship's

side will make her go over. If she goes over far enough to take water on her deck she is likely to fill up and must be raised. If a ship grounds at or near low tide she is not likely to turn over and can generally be floated when the tide rises; if she grounds near high tide her condition may become serious when the tide falls. Salvage methods come properly under the subject of Seamanship.

The ship of Plate II grounds during ebb tide on a gently sloping beach, draft 18 ft. forward and aft. $GM = 2$ ft. The tide has three more feet to fall. Is she in danger of turning over?

$$W = 8820 \text{ tons}$$

$$KG = KM - GM = 26.55 - 2.0 = 24.55 \text{ ft.}$$

$$\text{At low water, draft} = 15 \text{ ft. and } W' = 7100 \text{ tons}$$

$$KM_1 = 28.33 \text{ ft.}$$

$$KG' = \frac{W \times KG}{W'} = \frac{8820 \times 24.55}{7100} = 30.50 \text{ ft.}$$

$G'M_1$ is therefore negative. The ship will surely take a list and may turn over. To prevent this, steps should be taken to reduce the height of the center of gravity, such as lowering boats into the water or filling the double bottoms.

40. Free surface. Cargo which is properly secured retains its position relative to the ship regardless of the ship's position. Cargo such as grain, coal and ore in an incompletely filled hold **may** shift from side to side when the ship rolls, liquid in an incompletely filled tank is **certain** to move from side to side when the ship rolls. The effect on stability of both of these is the same, and the reason is that in each case a weight is added on the descending side which increases the inclination reached before the ship starts to return and resists the ship's tendency to right herself. Consider the ship in Fig. 14. When she has rolled over so that her new waterline is $W'L'$, the level of the liquid in the tank changes from wsl to $w'sl'$ because the surface of the liquid remains horizontal. An amount of liquid represented by the wedge $ws w'$ has been removed from the high side and added to the low side. Clearly such a shift of weight increases the angle to which the ship lists before she reaches a position of equilibrium. Further, the weight added on the low side which must be lifted when the ship starts swinging

back toward the erect position resists the swing back and thereby resists the tendency of the ship to right herself.

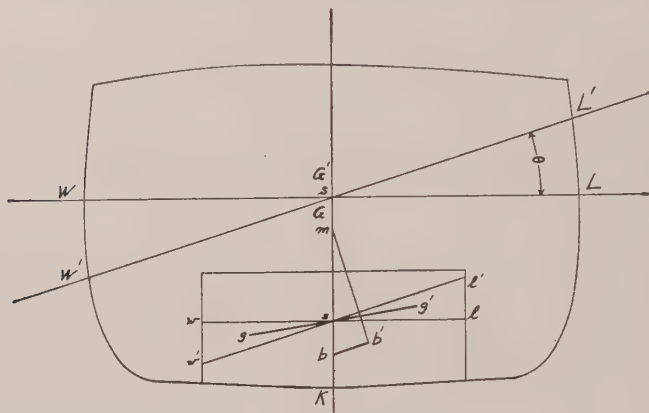


FIG. 14.—FREE SURFACE.

The reduction in metacentric height due to free surface is mathematically equal to $\frac{35}{36} \delta \frac{i}{V}$

where δ = density of liquid having free surface

i = moment of inertia of free surface

V = volume of displacement of ship.

When the liquid is sea water this value reduces to $\frac{i}{V}$.

When the free surface is rectangular in shape (which is usually the case),

$$i = \frac{1}{12} b^3 = \frac{\text{length} \times (\text{breadth})^3}{12}$$

It should be noted that the **amount** of liquid in the tank has no effect on the reduction of GM, but only the moment of inertia of the free surface. This is because the volume of liquid added to the low side depends **not** on the **amount** in the tank but **solely** on the **angle of inclination**. The reason that free surface reduces stability is that water runs down hill and therefore when a free surface is present a weight is added on the descending side of the ship which tends to capsize her.

It is impossible to avoid having a free surface in some tanks. The effect of this free surface is reduced by fitting longitudinal bulkheads in such tanks. Since i varies as the cube of the breadth, it follows that if the tank in Fig. 14 is divided in two parts by a longitudinal watertight bulkhead, the reduction in GM due to a free surface in each of these two tanks will be only **one eighth** the reduction without this bulkhead. And if there is a free surface in both, the reduction of GM is **one fourth** of what it would be if they were one tank.

41. Bilging. When a ship is bilged, a part of her volume which formerly was buoyant ceases to give any buoyancy. The water taken in is just so much added weight which causes the ship to sink deeper, thereby reducing her freeboard. If the compartment bilged is located at the midlength and extends equal distances both sides of the centerline, the water taken in will produce straight sinkage just as any other weight added in this location. This sinkage is equal to the volume of lost buoyancy (i.e. the volume of the bilged compartment below original waterline) divided by the area of intact waterline (i.e. waterline area of intact compartments). If the bilged compartment is a hold or main machinery space the buoyancy lost may be equal to the reserve buoyancy of the ship provided by her freeboard. In such a case the ship sinks.

In addition to the **loss of buoyancy** by bilging there will be a **reduction in stability** due free surface in the bilged compartment. There will be a change in metacentric height which may be either an increase or decrease depending upon whether the center of gravity of water added is above or below the center of gravity of the ship.

The admission of water to a compartment will produce list and change of trim unless the bilged compartment is exactly central in the ship. If the compartment is in one end, that end of the ship may be brought under the water. If the flooded compartment is on one side of the centerline, the inclining moment due to the added water may exceed the maximum righting moment of the ship, in which event she will turn over. When the compartment is only on one side we have the most unfavorable condition because as the ship lists, more and more water is admitted to the bilged

compartment increasing the inclining moment and the list reached. The inclining moment builds up as the ship goes over and unless she has a high maximum righting moment will capsize.

SECTION D—STABILITY CURVES

42. Computation of righting moment. The point of intersection of the line of action of the force of buoyancy when the ship is erect and that when it is inclined a **small** amount is the metacenter. For such small angles the righting moment is $W \times GM \sin \theta$. If this were the value of the righting moment for all angles of inclination the ship would have her maximum righting moment when θ equals 90° (ship on beam ends) and a zero right-

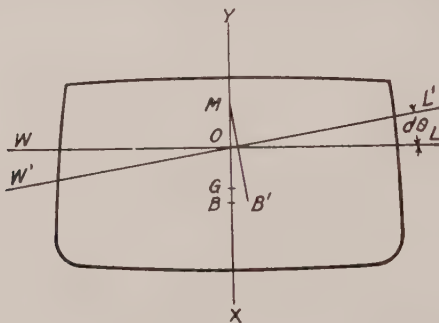


FIG. 15.—IMMERSED AND EMERGED WEDGES.

ing moment only when θ equals 180° (ship upside down). In other words, the intact ship could not be capsized. That such is not actually the case is a matter of common knowledge.

For inclinations of 10° or less the intersections of the verticals through the centers of buoyancy in the erect and inclined positions are almost exactly in the same point,—**almost but not exactly**. As the inclination is increased, this point of intersection moves closer to G. The movement of the point of intersection towards G, which is scarcely perceptible when θ is 10° or less, becomes apparent when θ is increased beyond 10° . Since the distance between G and the line of action of the force of buoyancy in the inclined

position is not constant, any calculations based on the assumption that this distance is constant gives erroneous results.

The change of moment due to inclining the ship is equal to the sum of the moments of the emerged and immersed wedges about an axis through O .

The sum of the moments of these wedges is equal to the difference between the moments of the volumes below $L'O$ and $W'O$ or the net moment of the volume below $W'OL'$ about an axis through O . It follows then that if the center of gravity of the ship, G , is located at O , the moment of the volume below $W'OL'$ about G is the righting moment of the ship and that this moment divided by the volume is the righting arm of the ship.

As soon as the angle of inclination becomes appreciable, for constant displacement, the old and new waterlines will not intersect in the centerline plane of the ship because due to the curvature of the ship there is no reason why $W'O$ should equal OL' and WW' should equal LL' and in general therefore these two conditions will not be fulfilled.

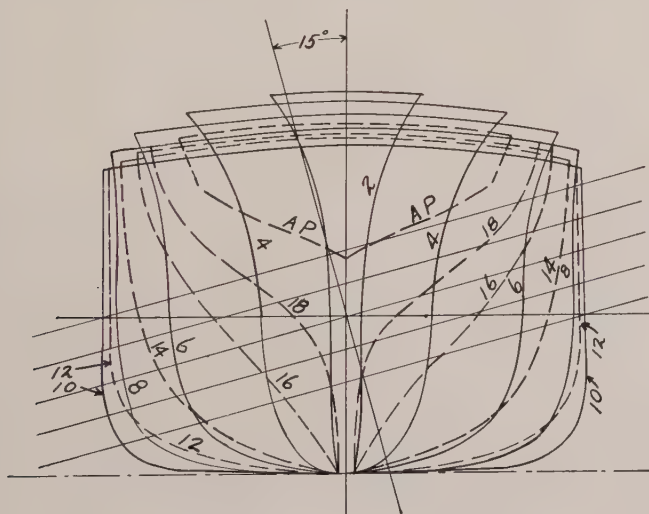


FIG. 16.—DOUBLE BODY PLAN.

43. Cross curves of stability. The practical methods of calculating the righting arms for various angles of heel are based on

the above facts. The method used generally is known as the method of cross curves. A double body plan is drawn similar to that of Plate I except that the deck is added. G is assumed to be at the designer's waterline. This is usually an incorrect assumption but the values of the righting arms can be easily corrected after the exact location of G has been determined by the inclining experiment. The exact location of G can only be determined after the ship is built; we must know the stability characteristics of the ship before any work is done. One or more waterlines are drawn above

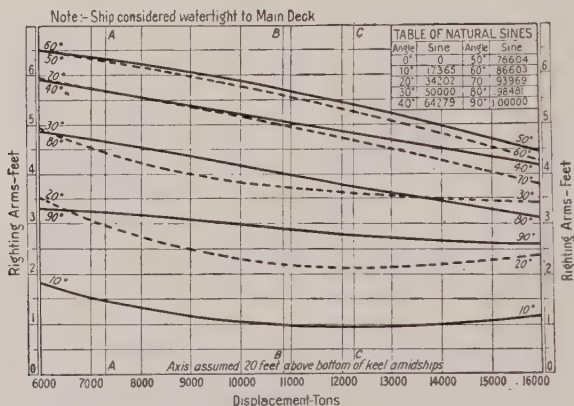


FIG. 17.—CROSS CURVES.

and below the designer's waterline as shown in Fig. 16. These water lines are revolved about G as a pole. Manifestly this is the same as revolving the ship in the opposite sense. As a matter of fact, the waterlines are drawn on tracing cloth and pinned to the double body plan at G . The waterlines are then revolved by steps of 10° or 15° up to 90° or further. For each setting of the waterlines (i.e. each assumed inclination of the ship) we compute the volume up to each waterline and the moment of that volume about an axis through G . The quotient obtained by dividing the latter by the former is the righting arm for that displacement and angle of inclination.

If we assume the ship to revolve about an axis through G , the volume of displacement in each of the inclined positions will be different from each other and from that in the upright condition

because of the **inequality of the immersed and emerged wedges in each case**. For each inclination therefore we can plot a curve of righting arm against displacement. A series of such curves is shown in Fig. 17. These curves are known as the cross curves of stability.

44. Curves of statical stability. Curves which show for any given condition of loading the righting arms at various angles of heel are of more value to the operating officer than the cross curves of stability. Such curves are known as curves of statical stability. They are obtained from the cross curves by intersecting the latter

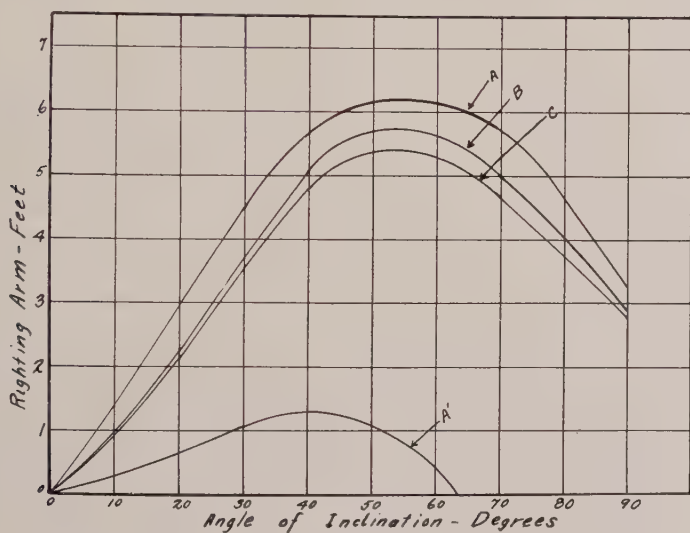


FIG. 18.—CURVES OF STABILITY.

by lines of constant displacement and plotting the values so obtained as ordinates against angles of heel as abscissæ. In Fig. 17, the line AA is a line of constant displacement which intersects the various cross curves. The values of the righting arms from Fig. 17 have been plotted in Fig. 18 with angles as abscissæ giving curve A. Curves B and C of Fig. 18 were similarly obtained from Fig. 17.

There is no reason why the center of gravity of the ship at

12,750 tons displacement should be in the same position as that at 7,300 tons displacement. Therefore, in general, the center of gravity of the ship will be in a different location for each displacement. The cross curves of stability were obtained on the assumption that the center of gravity remained fixed. If now, we wish to get a true representation of the values of the righting arm at various inclinations, we must apply the correction $OG \sin \theta$ to the values obtained from curves A, B and C of Fig. 18 and plot

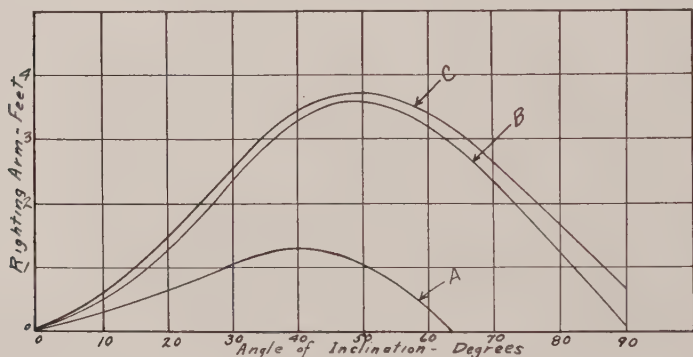


FIG. 19.—CURVES OF STATICAL STABILITY.

new curves using the corrected values of righting arm. OG is the distance between the assumed and true location of the ship's center of gravity. This has been done on Fig. 18 for curve A only. Curve A' has been obtained from curve A by applying the correction $OG \sin \theta$ to all ordinates of curve A. In this case and usually the correction is subtractive. The true value of righting arm is less than that obtained directly from the cross curves; the maximum righting arm is materially less and at large inclinations the difference is very pronounced. The complete set of curves of statical stability for the ship of Plate I and Fig. 16 is shown in Fig. 19.

45. Initial stability and range of stability. For small angles of inclination the righting arm is $GM \sin \theta$. It follows therefore that the ease with which a ship may be given a small inclination depends upon the magnitude of GM . **In other words the initial stability depends upon the value of GM .** Ships having large

values of GM require the application of a large moment to give them an initial inclination. Ships having a small value of GM may be given an initial inclination much more easily. It does not follow that the ease with which a ship may be given an initial inclination is any criterion of its safety. **The safety of the ship if uninjured depends primarily on the range of stability, which may be defined as the angle to which a vessel may be inclined before the righting arm becomes negative.**

The range of stability does not depend entirely upon the transverse metacentric height; the **freeboard** has a material influence on the range of stability. The righting moment at any angle of heel depends upon the sum of the moments of the immersed and emerged wedges. This moment depends upon the volumes of the wedges and the distances of their centers of gravity from the point O of Fig. 15. Up to the inclination at which the deck edge becomes immersed these wedges are roughly triangular in shape. The distance of their centers of gravity from O remains practically constant but their volume increases so that their moment increases. After the deck edge becomes immersed the wedges become roughly quadrangular in shape. Their volume continues to increase but their centers of gravity move toward O . These two tendencies have opposite effects upon their moment but the motion of the centers of gravity has the greater effect and the righting moment decreases. The maximum righting arm usually occurs shortly after the deck edge goes under. As the angle of inclination increases beyond this point there is a steady reduction in the righting arm and the net result is that the range of stability is about twice the angle at which the maximum righting arm occurs. The angle at which the deck edge is immersed depends directly upon the freeboard.

SECTION E—STABILITY IN OPERATION

46. Effect of loading on stability. The influence of the various elements of form on the stability characteristics of a ship have been touched upon. They may be summarized as follows:

(a) Initial stability depends upon (1) Shape of underwater body since this determines height of center of buoyancy above base line and therefore influences height of metacenter above base line, and (2) Beam and area of waterline since these affect the value of the metacentric radius, BM.

(b) Range of stability depends on the above and the freeboard.

The loading has a very important influence on stability since it is the factor of greatest importance in determining the center of gravity of the ship. In general it may be said the location of M depends upon form and is therefore beyond the control of the operator, but the location of G depends upon the loading and is therefore to a certain extent subject to the control of the operator. There are several governing principles which should be kept in mind.

Cargo should always be secured or disposed to prevent possibility of its shifting when the ship rolls. This is particularly important in the case of liquid and semi-liquid cargoes. The effect of free surface was discussed in *Art. 40*. Apart from the reduction of stability by free surface, the force of liquid striking the deck subjects the structure to severe strain and may start it. This has actually occurred. The necessity of properly securing heavy weights, such as locomotives, is apparent.

Keeping the center of gravity low results in a large value of GM and unpleasant rolling. This is of little consequence in a freighter usually but is of considerable importance in ships carrying passengers or live animals. In freighters it is usually good practice to dispose heavy weights in the bottoms of holds and put lighter cargo on top. Ships have seldom come to grief due to too much GM, but lack of it has often caused their loss. However, the comfort of passengers must be considered and ships with large values of GM are likely to be bad rollers.

The stevedores are responsible for the proper stowage of the cargo including its disposition and securing, but this fact will be small consolation to the master who finds his ship in an unstable condition in mid-ocean because the stevedore did not do his job properly. A wise master will watch the stowage and securing of the cargo. In cases where the ship carries cargo of one kind such as bananas, sugar, wheat, etc., there is little the master can do

except to see that the spaces are filled or where partially filled that substantial partitions are erected to restrain the cargo in the places it is put. Particular attention should be given to the securing of cargo carried on deck, such as lumber and cotton. Deck cargo is difficult to secure adequately against shifting and shifting of deck cargo is dangerous both to ship and personnel. Cargo shifting in the hold may give the ship a dangerous list or in extreme cases cause her to capsize, but a shifting deck cargo, in addition, may cause the loss of some of the crew. Further the fact that deck cargo is a high weight and therefore raises the center of gravity of the ship and reduces the metacentric height should not be forgotten.

A problem which requires thought is the proper disposition of miscellaneous cargo. In general, dense cargo such as steel (rails, bars, plates, billets) should be stowed in the bottom of the holds and lighter cargo on top. Such stowage will tend to increase the metacentric height by lowering the center of gravity of the ship which will give her greater initial stability. If this is not possible because the heavy cargo is to be discharged before the lighter cargo, and the former must therefore be stowed in the 'tween deck spaces, certain or all of the tanks in the double bottom space should be filled to compensate for the loss of metacentric height. When this is done the tanks must be filled right up in the sounding tubes because if they are not 100% full the loss of initial stability due to free surface added to that due to having the top weights heavy may be serious.

Another type of problem which may arise is as follows: A ship is to visit several ports in succession discharging and taking on certain cargo at each and finally discharging completely at the last port where the depth of water is very little greater than the load draft of the ship. This type of problem requires the keenest thought and most careful consideration due to the conflicting requirements to be met. Of course, the cargo to be discharged first must be on top and the cargo taken on at the first and subsequent ports must not cover cargo to be discharged before reaching the last port where the ship is entirely discharged. Adequate stability on each leg of the voyage must be provided by keeping the heavier cargo low and restriction of deck cargo. Further the ship should

be as nearly as possible on an even keel when entering the last port, for if she has any considerable trim her extreme draft may be greater than the depth of water even though her mean draft be less than her mean load draft.

Just as the reduction of metacentric height due to carrying heavy cargo high up in the ship may be compensated by admitting ballast water to the double bottom tanks, similarly an undesirable trim may be wholly or partially corrected by admitting ballast water to the forward or after peak tanks. However, in the addition of any ballast to a ship which is close to her marks or close to the permissible draft at a particular port, consideration must be taken of the increase in draft due to such additional weight.

All of the problems presented herein can be solved as problems in simple arithmetic by application of the principles and formulas of *Arts. 36, 37 and 38*. A few examples are given to illustrate this. If practicable the admission of water ballast should be deferred until the ship is clear of the harbor so that good, clear water free from mud and débris may be admitted.

Example: The ship of Plate II is required to load 200 tons of structural steel in her #2 'tween decks. What addition of ballast water in the double bottom tanks is required to offset the reduction of GM due to carrying this heavy cargo so high? The center of gravity of the steel is 34 feet above the keel. Hold #2 is 40 feet deep and the double bottom tanks are 36 inches deep.

Solution: Taking the center of gravity of the hold at its mid height which is $\frac{1}{2}$ of $40 + 3$ ft. = 23 feet above the keel, the center of gravity of the steel is $34 - 23 = 11$ feet above the center of gravity of the hold. Similarly the center of gravity of the ballast water is $\frac{1}{2}$ of $40 + 1.5$ ft. = 21.5 feet below the center of gravity of the hold. The vertical moment of the ballast water about the center of gravity of the hold should equal that of the steel to keep the center of gravity of the contents of the ship in this location the same as it would be if the hold were filled with a homogeneous cargo.

Let B = number of tons of ballast water required.

Then $21.5 \times B = 200 \times 11$

And $B = \frac{200 \times 11}{21.5} = 102 \text{ tons.}$

Example: The ship of Plate II when laden with a cargo of cotton in the holds and 500 tons deck cargo has a draft of 25 feet forward and 24 feet 4 inches aft, mean 24 feet 8 inches, which is four inches less than mean load draft. The center of gravity of deck cargo is 5 feet above upper deck which is 42 feet above keel. It is desired to compensate for deck cargo by water ballast in the double bottom tanks which are 3 feet deep. Can this be done without exceeding load draft?

Solution: Distance from center of gravity of hold to center of gravity of deck cargo $= 5 + \frac{1}{2} (42 - 3) = 24.5$ feet.

Vertical moment of deck cargo about center of gravity of hold $= 500 \times 24.5$.

Distance from center of gravity of hold to center of gravity of ballast tanks $= \frac{1}{2}$ of 42 = 21 feet.

$$B = \frac{500 \times 24.5}{21} = 583 \text{ tons.}$$

Tons per inch = 51.

Therefore increase of mean draft due to ballasting $= \frac{583}{51} = 11.4$ inches.

Therefore ballasting cannot be done without exceeding load draft.

Example: The ship of Plate II has the following drafts: 22 feet forward, 25 feet aft, 23 feet 6 inches mean. She has to cross a bar where depth at high water is 25 feet and pilot wants a maximum draft not to exceed 24 feet. Fore peak is empty. Can she do it?

Solution: Moment to alter trim 1 inch is 1260 ft. tons.

Distance from center of gravity of fore peak to midship section is 220 feet.

Therefore a change of trim of 1 inch requires addition of $\frac{1260}{220} = 5.72$ tons of water in fore peak.

To bring the ship to even keel requires addition of $36 \times 5.72 = 206$ tons of water in fore peak.

Tons per inch = 50.5.

Therefore addition of 206 tons of water in fore peak will cause an increase in mean draft of $\frac{206}{50.5} = 4.1$ inches and gives the ship

a draft forward and aft of 23 feet, 10 inches, which is 2 inches less than maximum permissible draft of 24 feet.

47. Importance of watertight integrity to stability. Water may enter the ship due to damage produced by the elements, collision, cargo getting adrift or attack by gun or torpedo. The only method of limiting the amount of buoyancy and stability lost by such damage is by dividing the ship into watertight compartments. As far as practicable centerline bulkheads should be eliminated. Or if present for structural or other reasons should have their watertightness destroyed by holes at the bottom, due to the serious upsetting effect of water suddenly added on one side of the ship.

Transverse bulkheads should be intact up to the highest watertight deck. **Experience has taught that watertight doors are not to be depended upon.** They are nearly always open when they should be closed. The spacing of the bulkheads should be such that the flooding of any one compartment regardless of position in ship will not immerse any part of the highest watertight deck. It is desirable that a ship should be able to withstand the flooding of two compartments because the damage may be so close to a main transverse bulkhead that its watertightness is destroyed. This requirement can be met on large passenger ships but not on most freighters.

Fore and aft passageways such as shaft alleys are a source of great danger when the ship is bilged. They should be provided with watertight doors which should be kept **closed watertight** at all times.

Watertight partitions, doors and hatches should be kept watertight. The gaskets of doors and hatches should be examined periodically and renewed when the rubber has lost its life. No holes in watertight decks or bulkheads should be permitted unless provision is made for **closing them watertight.**

To failure to observe the precautions listed in this article most of the peace time marine disasters may be traced.

SECTION F—ROLLING

48. Rolling among waves. Suppose a ship is floating at rest in still water. A wave system approaches from the left. As the wave disturbance moves by the ship the surface of the water changes from the horizontal. Take the case when the ship is at the mid-height of the wave, Fig. 20A. Fig. 20B is an enlarged view of Fig. 20A and shows more clearly what has happened.

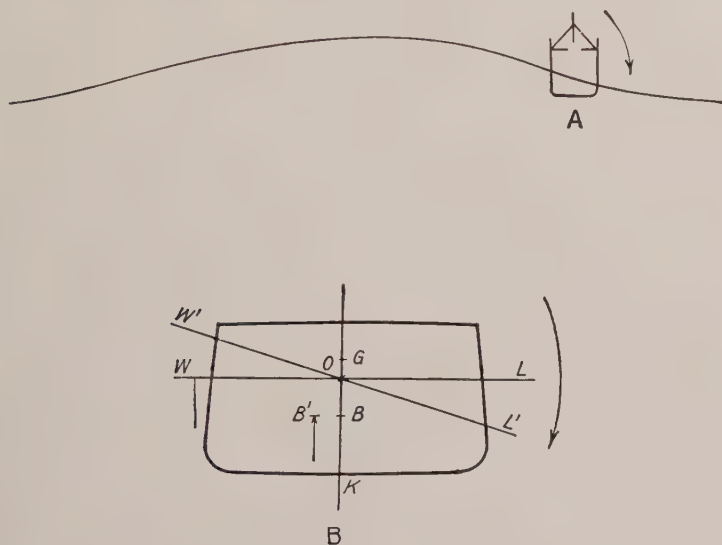


FIG. 20.—SHIP AMONG WAVES.

The volume of displacement has changed shape from $WOLKW$ to $W'OL'KW'$ and consequently the center of buoyancy has moved from B to B' . We have then a couple tending to incline the ship from the vertical in such a manner as to make her water-line parallel to the wave surface. This tendency is present whenever the surface of the water is not perpendicular to the plane of symmetry of the ship.

It is easy to see that if the time required for the ship to make a complete oscillation is the same as that required for the wave to move one wave length to the right the surface of the water

in each case is such as to roll the ship in the direction that she is moving. The phenomenon of synchronism is familiar to anyone who has studied elementary physics. The great amplitude of oscillations which can be produced by oscillations of insignificant amplitude when synchronism exists is well known. So in a ship, if the natural period of the ship and waves is the same, the angle of roll tends to increase at a constant rate, and were it not for two things would soon cause the ship to roll over. The two things which prevent this catastrophe are (1) the friction of the water on the side of the ship consumes energy, (2) as the angle of roll increases the period of roll changes so that exact synchronism ceases when the angle of roll reaches a certain point which varies with individual ships.

49. Relation between period of roll and metacentric height.

The period of roll is the time in seconds for a roll from starboard to port or vice versa. It has been proved both theoretically and practically that the **period of roll varies inversely as the square root of the metacentric height**. That is, if a ship has suffered much damage that her period of roll has **doubled**, GM has been reduced to **one quarter** of its value prior to the injury. This is also the explanation for the fact that ships with large metacentric height are bad rollers and not satisfactory as passenger ships.

The value of the metacentric height of a ship may be determined by the following formula which was developed by the Navy Department to determine the GM of merchant ships taken over during the World War.

$$GM = \frac{c^2 B^2}{T^2}$$

Where GM = transverse metacentric height in feet

c = a constant = 0.22

B = beam in feet

T = period as defined above

If a ship suffers damage, her master has but to observe the effect on her period of roll to make a fairly accurate estimate of the loss of stability. From that and the state of the sea

and the weather prospects he can make an intelligent decision regarding the necessity of abandoning his ship.

50. Anti-rolling devices. There are several practical means for damping the rolling of ships:

(a) Bilge keels, (b) Anti-rolling tanks, (c) Moving weight, (d) Gyro stabilizer.

The first of these, bilge keels, tends to extinguish rolling by the resistance to its motion offered by the water; the second, anti-rolling tanks, by reducing the righting arm; the third, moving weight, by opposing the swing back past the normal; the fourth, by the well known property of a gyro to resist rotation of its axis.

(a) Bilge keels. Bilge keels are installed on nearly all ships. Their ability to reduce rolling has been proved by rolling ships with bilge keels of different depths and without them.

(b) Anti-rolling tanks. Anti-rolling tanks have been installed on some merchant ships. They have in general given satisfactory service. The objections to them are that they reduce rolling by opposing the ship's tendency to right herself, space required and difficulty of control.

(c) Moving weight. There have been few installations of mechanical stabilizer which have operated satisfactorily and those for small vessels only. It consists of a device for moving a weight toward the rising side. The principal objections are danger of loss of control, space and weight required.

(d) Gyro stabilizer. While entirely satisfactory operation of a gyro stabilizer has not yet been secured, it is the form of apparatus most in use today and a number of installations have been made. Rolling tends to change the plane of rotation of the gyroscope which opposes this tendency by its rotational inertia. The principal objection to it is its weight. The principal difficulties with existing installations have been in technical details such as lubrication, facility of control, etc. It is, however, positive in action and takes less space than either anti-rolling tanks or moving weight.

Problems

37. A coal lighter is box shaped, having the following dimensions: length, 110 feet; beam, 30 feet; depth, 8 feet. What is the height of the transverse metacenter above the base line in the light condition, draft 18 inches?

Ans. 50.75 ft.

38. What is the height of the longitudinal metacenter above the base line of this coal barge in the loaded condition, draft 4 feet?

Ans. 254 ft.

39. A caisson of cylindrical cross section is 50 ft. long and 15 ft. in diameter. It is being towed with its axis at the waterline. What is the transverse BM?

Ans. 3.18 ft.

40. A box shaped lighter 75 feet long, 28 feet broad, has a displacement of 360 tons. What is the height of the transverse metacenter (M) above the keel?

Ans. 13.8 ft.

41. The half ordinates of a yacht measured at intervals of 6 feet are 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet. The displacement is 78 tons. What is BM?

Ans. 9.54 ft. Simpson's First Rule; 9.51 ft. Trapezoidal Rule.

42. Half breadths of the designer's waterline of a gunboat are 0.1, 1.7, 3.8, 6.3, 9.2, 11.9, 14.4, 16.3, 17.9, 18.9, 19.3, 19.1, 18.7, 17.7, 16.3, 14.4, 12.3, 9.9, 7.2, 4.1 and 0.3. The distance between stations is 11.6 feet. The mean draft is 12 feet and the corresponding displacement 1,500 tons. What is the height of the transverse metacenter above the center of buoyancy?

Ans. 8.74 ft.

43. Refer to Plate II and determine the metacentric radius (BM) for the vessel when her draft forward is 20 ft. and aft 21 ft.

44. Refer to Plate II and determine the moment of statical stability for this vessel when she is in salt water, draft forward 24 feet, aft 26 feet; assuming that the center of gravity is two feet above waterline plane at midship section, with vessel listed over 10° .

Ans. 375 ft. tons.

45. A tanker is inclined in the light condition, displacement 6,700 tons, by moving a weight of 60 tons a distance of 25 feet from the center line. In the inclined position the deflection of a 21 foot plumb bob is $4\frac{3}{8}$ inches. What is the transverse metacentric height in this condition? If the transverse metacenter is 26 feet above the base line, what is the height of the center of gravity?

Ans. $GM = 12.91$ ft.; $KG = 13.09$ ft.

46. The scout cruiser *Detroit* has a displacement of 7,100 tons with a mean draft of 13'6". The center of gravity is at the waterline. She is placed in dry dock, but with the dock flooded, and carefully brought to an even keel (no list). A 40 ton weight is then moved 50 feet across the deck and produces a list of 5 degrees. What is the height of the transverse metacenter above the keel?

Ans. 16 ft. $8\frac{1}{2}$ in.

47. You are required to conduct an inclining experiment on a vessel whose displacement is 8,500 tons. The only weight available is 40 tons and the width of the deck when it can be moved is 50 feet. You know that GM is not over 4 feet. How long a pendulum will you use in order that it will not swing more than 6 inches in each side of the perpendicular position?

Ans. 17 ft.

48. A scout cruiser is 550 feet long and longitudinal GM is 480 ft. Displacement is 7,000 tons. What will be the change of trim if 50 tons of fuel oil is transferred from forward aft a distance of 300 feet?

Ans. 29.4 in.

49. A vessel of 3,100 tons is 280 feet long and has a draft forward and aft of 15 feet. Her longitudinal GM is 326 feet. How many tons of cargo must be moved from a forward to an after hold to give her a draft forward of 14 feet? The distance between centers of the holds is 180.5 feet.

Ans. 40 tons.

50. You are on a vessel 300 feet long with a displacement of 2,000 tons. Determine the approximate weight of fuel oil which would have to be transferred from forward aft so as to decrease her draft forward 6 inches. The distance from center to center of the tanks is 200 feet. Longitudinal $GM = 300$ feet.

Ans. 10 tons.

51. What will be the moment required to change the trim of the following vessel 6 inches: Displacement, 17,300 tons; Length, 420 feet; Longitudinal BM, 452 feet; c.g., 10 feet above C. B.?

Ans. 9,103 ft.-tons.

52. A vessel 300 feet long with a displacement of 2,100 tons has a longitudinal GM of 480 feet. Find the moment to change trim one inch.

Ans. 280 ft.-tons.

53. The longitudinal metacentric height of the U. S. S. *Omaha* in normal condition (displacement 7,500 tons) is 1,206 ft. The length between perpendiculars is 550 feet. The draft is 14 feet 4 inches forward and 14 feet 2 inches aft. Assuming the center of flotation at the dead flat, what will these drafts be after shifting 50,000 gallons of oil from forward to after tanks, a distance of 40 frame spaces (160 ft.)? 300 gallons of fuel oil weigh 1 ton.

Ans. 13 ft. 6.27 in. forward; 14 ft. 11.73 in. aft.

54. A ship has a displacement of 7,300 tons. Her transverse GM is 3'3". She has a list of 8 degrees to port. How many gallons of water would it be necessary to pump from a port to a starboard tank to bring the ship to an even keel? The athwartship distance between the center of gravity of the water tanks is 30 feet. 269 gallons of water equal 1 ton.

Ans. 29,886 gal.

55. Your vessel is to go in dock. She has a list of 3° to port. Her displacement is 30,000 tons and GM is 5 feet. How many gallons of fuel oil will you pump from No. 4 fuel oil tank to No. 3, the distance between centers of these tanks being 60 feet, in order to bring her to an even keel? One gallon of fuel oil weighs 8 pounds.

Ans. 36,680 gal.

56. A yacht of 1,000 tons, with a GM of 2.28 feet, is to be righted preparatory to going into dry dock; she has a 5° list to starboard. How many gallons of oil must be pumped from the starboard to the port side? The distance from center to center of the tanks is 20 feet and one gallon of oil weighs 8 lbs.

Ans. 2,800 gal.

57. The cargo of a tanker is 600 tons gasoline and 7,500 tons fuel oil and the height above the base line of the center of gravity of this cargo is 19 feet. If the transverse metacenter is 22.5 feet

above the base line, what is her transverse metacentric height in the full load condition? See Prob. 45.

Ans. 6.19 feet.

58. Given the following data for a yacht. Draft forward, 9 ft.; draft aft, 9 ft. 8 inches; length between perpendiculars, 310 ft.; displacement, 1215 tons; tons per inch, 15.5; longitudinal metacentric height, 550 ft.; transverse metacentric height, 2.5 ft.; center of flotation and center of gravity, 5 ft. abaft midship section; condition, even keel. What will be her drafts and inclination if machinery weighing 26.3 tons is placed 32 feet abaft the dead flat with its center of gravity 4 feet to port of the centerline of the ship?

Ans. 8 ft. 11.7 in. forward; 9 ft. 11.6 in. aft; $\theta = 2^\circ$.

59. A barge, $80' \times 30' \times 10'$, drawing 3 feet in salt water has a turbine rotor weighing 8 tons on the deck with its center of gravity 9 feet over the center of gravity of the barge. What will be the maximum draft when the rotor is rolled off of one end?

Ans. 3 ft. 4.28 in.

60. A yacht grounds on a gently sloping beach during ebb tide having a draft of 9 ft. 8 inches. The corresponding displacement is 1277 tons; the tons per inch, 15.5; the transverse metacentric height, 2.5 ft.; the height of the center of gravity above the keel line, 10 ft.; and the tide has 20 inches to fall before low water is reached. Is the ship in danger of turning over? Neglect change in height of M.

Ans. Yes.

61. The S. S. *California* of 30,000 tons has a GM of 3 feet. A small amount of fuel oil is consumed from two tanks, leaving 15,000 gallons of oil in each one. Each tank extends 40 feet fore and aft and 30 feet on each side of the center line. What is the new value of GM, neglecting the weight of the oil consumed? One gallon = 231 cu. in. $\delta = 0.92$.

Ans. 1.77 ft.

62. A yacht has a displacement of 1,200 tons and a transverse metacentric height of 2.3 feet with all oil tanks completely filled. A small amount of oil is consumed from several tanks which extend 15 feet on each side of the center line and 40 feet fore and aft. What will the transverse metacentric height then be? $\delta = 0.92$.

Ans. 0.38 ft

63. The cargo tanks of the tanker of Problem 57 have a horizontal area of 6,300 sq. ft. and a mean width of 28 ft. If we take i equal to $\frac{1}{12}$ of the area times the square of the mean breadth, what is her metacentric height with a free surface in half of the tanks at full load displacement, 14,800 tons? $\delta = 0.92$.

Ans. 5.84 ft.

64. What would be the metacentric height of the tanker of problem 63 under the conditions of problem 63 if she had no centerline bulkhead so that the mean width of the tanks was 56 ft?

Ans. 4.79 ft.

65. A water barge has 4 transverse watertight bulkheads equally spaced. The dimensions of the lighter are: length, 110 ft.; beam, 30 ft.; depth, 8 ft.; draft, 2 ft. What is the effect of bilging the central compartment? What is the effect of bilging the three central compartments?

Ans. (a) Sinks 0.5 ft.; (b) 3.0 ft.

CHAPTER III

PROPULSION

SECTION A—RESISTANCE

51. Skin resistance. If one drops a chip of wood into a moving stream of water, it almost immediately acquires the speed of the stream and floats with it. The water holds the chip and makes it move with it by the friction of the water rubbing on the surface of the chip. If we tie a string to the chip and prevent it from moving away with the water, there will be a tension in the string which can be measured. Just as the rubbing of the water on the surface of the chip tends to stop relative motion between water and chip, so the rubbing of the water on the under-water surface of a moving ship tends to bring her to rest and must be overcome if the ship is to continue to move through the water at the same rate of speed. Except for ships driven at extremely high speeds, the skin resistance is more than half of the total resistance.

The friction between the ship's surface and the water in contact with it produces a drag on this water tending to pull it along with the ship. As a result, this water is given a motion in the same direction as the ship. This water which is moving with and following the ship is known as the **wake** or **wake current**. It has an important bearing on propulsion.

52. Stream lines. The relation between a ship and the water in which it is moving is exactly the same regardless of which is regarded as stationary. That is, the effect produced on still water by a moving ship is no different from that produced on water flowing in the opposite direction at the same rate of speed past a fixed ship. It is usually regarded as more convenient in discussions of stream lines to regard the water as moving and

the ship as being still. In Fig. 21, which represents the stream lines of a liquid flowing past a plane from right to left or of a

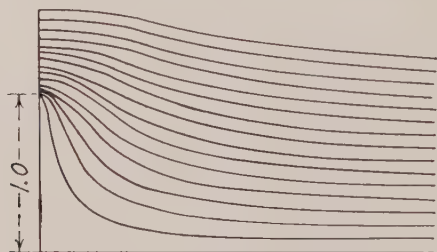


FIG. 21.—LINES OF FLOW AROUND PLANE.

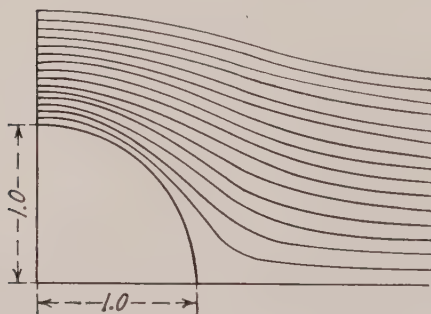


FIG. 22.—LINES OF FLOW AROUND CIRCLE.

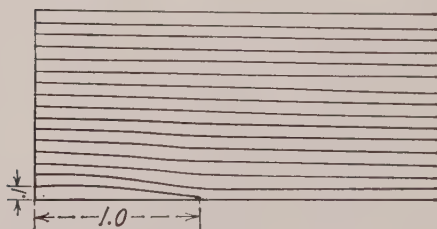


FIG. 23.—LINES OF FLOW AROUND ELLIPSE.

plane being moved to the right in a body of still water, the crowding of the stream lines at the edge of the plane is very perceptible. We get something like this effect in square ended lighters. Fig. 22 shows the stream lines for flow past a circular object such as a

can buoy and Fig. 23 the stream lines for flow past an elliptical cylinder having a semi-major axis of 1.0 and a semi-minor axis of 0.1. In the last case the crowding of the stream lines abreast the widest part of the cylinder is not perceptible to the eye. Fig. 23 resembles the waterline of a destroyer. The resistance due to distortion of the stream lines manifests itself in the formation of waves and eddies.

53. Wave making resistance. The formation of the bow wave by a moving ship is a familiar sight to anyone who has seen a ship underway. It is also common knowledge that to set up a

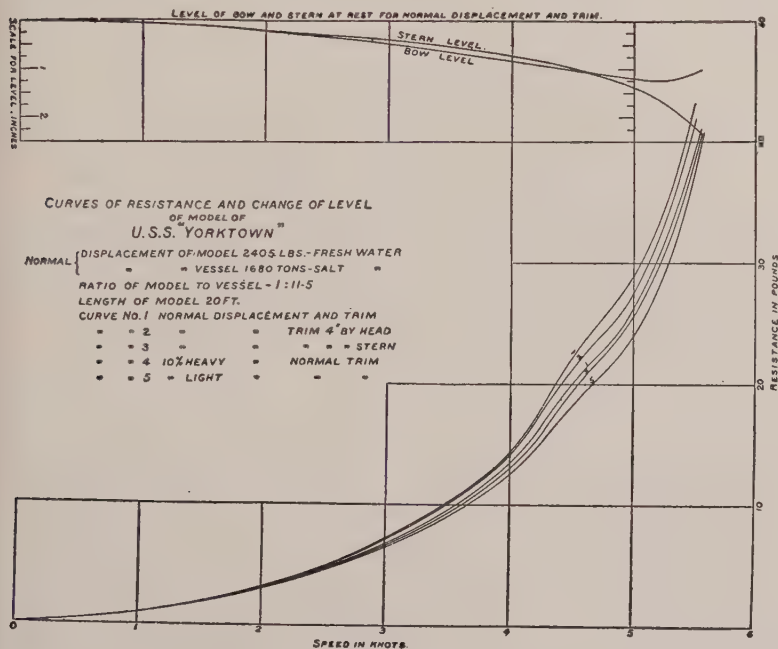


FIG. 24.—CURVES OF RESISTANCE.

wave disturbance requires the expenditure of energy. Sound, light and radiotelegraphy are examples of wave motion and we are all familiar with the fact that the production of these requires the expenditure of energy. Similarly the generation of the ship's wave system requires the expenditure of energy and this energy

comes from the ship. The resistance requiring this expenditure of energy or absorbing this expenditure of energy is called the wave making resistance. It is in all ships a large component of the total resistance and in the case of some high speed ships, particularly those which are relatively short for their speed, may be more than half of the total resistance.

In plotting curves of wave-making resistance it is found that they do not come out as smooth curves but at some definite points there are well defined humps or regions of unfairness. Fig. 24 shows such a hump at approximately 4.6 knots. The principal component of the wave-making resistance is the energy required

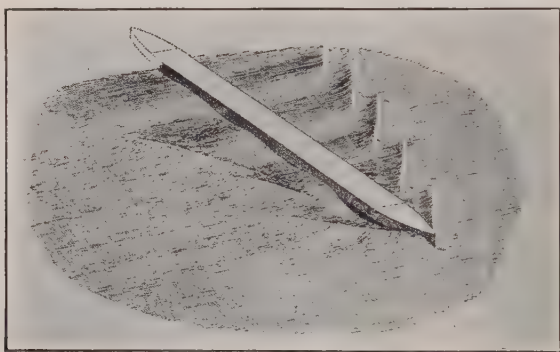


FIG. 25.—BOW WAVES.

to set up and maintain the bow wave and stern wave systems. Fig. 25 shows a special model made by Mr. William Froude to study the bow wave system of a ship. A similar system of waves is made by the action of the stern of the ship, but whereas the bow system is set up in undisturbed water the stern system is set up in water already in motion due to the bow wave system. When two or more wave disturbances take place simultaneously in any medium the result is one wave motion, the amplitude and period of which depend upon the amplitudes, periods and phase relation of the component waves. If two sound waves of exactly the same pitch (period) and loudness (amplitude) could be set up so that the second was half a period out of phase with the first, the result would be silence; if it was exactly in phase with the

first the result would be sound twice as loud as either one. Similarly with a ship, when its length is such that the crest of a wave of the bow system coincides with one of the stern system a big wave is produced requiring increased power for its propagation. This fact makes itself evident by a pronounced rise in the wave-making resistance of the ship which gives the humps on the resistance curves which have been mentioned. The wave-making resistance will be a minimum when a wave crest of the bow system coincides with a hollow of the stern system.

54. Eddy resistance; Air resistance. Eddy resistance is the resistance due to the formation of eddies such as those formed behind a blunt stern post or strut. When such is present the lines of flow of the water are broken and confused masses of eddying water take their place. The formation of these eddies utilizes energy which would otherwise help to propel the ship. In ships of good form it is a minor part of the total resistance.

For a proper analysis, air resistance should be divided into frictional, eddy and wave-making resistances but it is too small to warrant further analysis although the total air resistance is not always negligible.

55. Computation of frictional resistance. The amount of friction varies directly with the amount of surface, i.e. if one ship has twice the surface of an exactly similar ship the water will exert just twice the drag upon it when the two ships are propelled at the same speed. Also the frictional resistance varies with the speed, but not directly. It has been proved experimentally that frictional resistance varies as the speed to the 1.83 power ($V^{1.83}$). The amount of frictional resistance depends also upon the nature of the surface of the ship. A surface covered with shell-fish and sea-weed will offer greater resistance than a clean surface such as a ship has immediately after docking. The coefficient of friction of a surface is designated by "f."

To summarize:

R_f = frictional resistance

f = coefficient of friction of surface

S = area of wetted surface

V = speed of ship

n = power of speed according to which R_f varies (has been experimentally determined to be 1.83)

$$R_f = fSV^n$$

The quantities to be experimentally determined are f and n . These have been determined by several investigators by towing in model basins planes of different areas, having surfaces of various degrees of smoothness at different speeds. n has been found to be a constant having a value of 1.83. There have been prepared tables showing the values of f for planes of various lengths and various characters of surfaces. It follows then that all we need to know to calculate the skin resistance of a ship is the coefficient of friction, the wetted surface and the speed.

56. Computation of residuary resistance. In resistance calculations the wave-making resistance, eddy resistance and air resistance are combined and called the **residuary resistance**. Nearly all of the residuary resistance is wave-making resistance. The most satisfactory method of determining the residuary resistance of a ship is by running a model of the ship in a model basin. Numerous experiments have definitely established Froude's Law or the Law of Comparison by means of which, given the residuary resistance of a model, the residuary resistance of the full sized ship may be computed. Suppose we have a model whose dimensions are l , b and d and a ship geometrically similar to the model whose dimensions are L , B and D , then $L = \lambda l$, $B = \lambda b$ and $D = \lambda d$, where λ is a constant. If w is the displacement of the model $= \frac{alb d}{35}$ where a is the block coefficient, and W is the displacement of the ship $= \frac{aLBD}{35}$,

$$\text{then} \quad \frac{W}{w} = \frac{aLBD}{alb d} = \frac{a\lambda l \lambda b \lambda d}{alb d} = \lambda^3$$

Then if r_w is the residuary resistance of the model at a speed v , the residuary resistance of the ship, R_w , at a speed $v\sqrt{\lambda}$ will be

$$\lambda^3 r_w = \frac{W}{w} r_w.$$

This may be expressed as follows:

$$\text{If } \frac{\text{speed of model}}{\text{speed of ship}} = \frac{\sqrt{\text{length of model}}}{\sqrt{\text{length of ship}}}$$

$$\text{Then } \frac{\text{Residuary resistance of model}}{\text{Residuary resistance of ship}} = \frac{(\text{Length of model})^3}{(\text{Length of ship})^3}$$

Froude's Law:

THE RESIDUARY RESISTANCES OF SIMILAR SHIPS AT CORRESPONDING SPEEDS VARY DIRECTLY AS THEIR DISPLACEMENTS. CORRESPONDING SPEEDS ARE SPEEDS WHICH VARY DIRECTLY AS THE SQUARE ROOT OF THE RATIO OF LINEAR DIMENSIONS.

When a model is towed in the basin the dynamometer measures its total resistance. The skin or frictional resistance is then computed by the formula previously given and subtracted from the total leaving the residuary resistance, r_w , of the model. Then the residuary resistance, R_w , of the ship at speed $v\sqrt{\lambda}$ is $\lambda^3 r_w = \frac{W}{w} r_w$. The frictional resistance, R_f of the ship at speed $v\sqrt{\lambda}$ may be calculated in the same manner as that of the model and the total resistance of the ship at $v\sqrt{\lambda}$ then is $R_f + R_w$.

57. Curves of resistance. By running the model at a number of speeds and computing the total resistance of the ship at corresponding speeds a curve may be plotted showing for any speed within that range the resistance of the ship when having the displacement and trim corresponding to those of the model. By varying the displacement and trim of the model and running it at various speeds we may compute the total resistance of the ship in the corresponding displacement and trim. Fig. 24 shows a series of such curves for a model of the U. S. S. *Yorktown*.

Fig. 26 illustrates the method of passing from the curves of resistance of the model as shown in Fig. 24 to those of the full sized ship. AAA is the curve of total resistance of the model. Subtracting the frictional resistance from this curve, we obtain the curve of residuary resistance of the model BBB. By changing our scales of speed and resistance BBB may also be taken to represent the residuary resistance of the ship, since the shape of

the curves of residuary resistance of both ship and model are the same. If then we add to the residuary resistance of the ship its

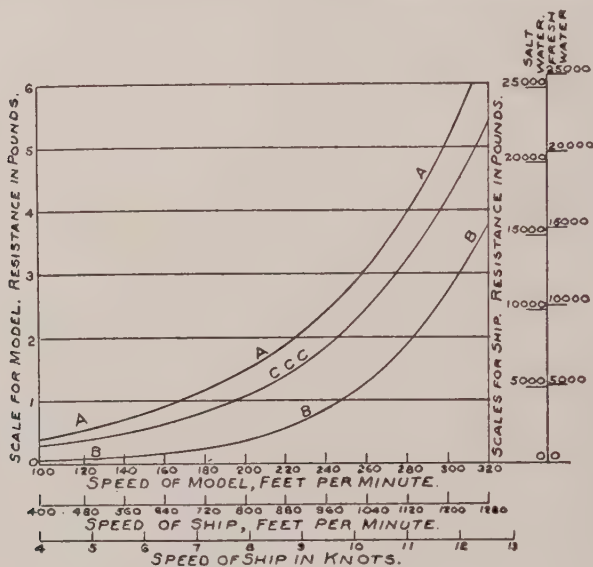


FIG. 26.—CURVES OF RESISTANCE.

frictional resistance, we obtain the curve of total resistance of the ship CCC.

58. Computation of power of propelling machinery. The resistance of the ship in pounds multiplied by the distance through which it moves in one minute gives the number of foot-pounds of work which must be delivered by the propellers per minute. This quantity divided by 33,000 gives the effective horse-power, E.H.P., of the ship. That is, the horsepower which must be delivered by the propellers to push the ship through the water. From this the indicated horsepower, I.H.P., or shaft horsepower, S.H.P., of the main engines may be determined.

Another method of computing the power of propelling machinery formerly used a great deal in England was by the Admiralty coefficient, C.

$$C = \frac{(\text{Speed})^3 \times (\text{Displacement})^{\frac{2}{3}}}{\text{I.H.P.}} = \frac{V^3 W^{\frac{2}{3}}}{\text{I.H.P.}}$$

Considerable experience is required in using the correct value of C for the new design. Further, this formula is only theoretically correct for speeds at which the total resistance varies as the cube of the speed.

SECTION B—CONDITIONS OUTSIDE OF SHIP AFFECTING RESISTANCE

59. Squat and change of trim. The drafts at the ends of a vessel floating freely in still water depend upon the amount the vessel weighs and the manner in which its weight is distributed. When underway changes in drafts occur without any change in weights. In the upper portion of Fig. 24 are two curves marked "Stern Level" and "Bow Level." These curves indicate the sinking which occurs at bow and stern when the model is towed at the speeds indicated. This is typical of what happens to all vessels in motion.

In order that measurements of the changes in height of a model's bow and stern may be applied to the full size ship, the speed is usually given in terms of the ratio $\frac{V}{\sqrt{L}}$ i.e. speed in knots divided by the square root of the length in feet, which is known as the speed-length ratio. As a result of a large number of observations it has been established that for speeds below that corresponding to a speed-length ratio of unity (4.5 knots in Fig. 24), a depression of both bow and stern occurs, the bow in general sinking a little faster than the stern. It follows then that within this value of speed-length ratio there is little change of trim, but that the ship squats bodily. Further increase in speed produces less sinkage of the bow and the bow begins to rise when the speed-length ratio equals about 1.20 (5.3 knots in Fig. 24). The stern continues to sink and it sinks more rapidly than the bow rises until $\frac{V}{\sqrt{L}}$ reaches a value of about 1.75. (Only scout cruisers and destroyers are ever driven to such a high speed.) During this period there is therefore a net sinkage of the ship and a very rapid

change of trim by the stern. The maximum settling at the stern is reached when the speed-length ratio equals about two, a speed only attained by destroyers. The bow continues to rise steadily. The center of gravity of a ship even a destroyer underway at full speed is practically always below its still position with reference to its original level. Ships sometimes appear to have raised themselves above their original level because one effect of a ship passing through the water is to depress the level of the water in contact with it. Sea sleds and other vessels of that type with exceedingly powerful engines actually raise their centers of gravity above their original level. The rapid change of trim and squatting which takes place in the range of speed-length ratio 1.20 to 1.75 is caused by the fact that in this range of speed the hollow of the bow wave moves aft from amidships to the stern, causing the stern to sink and the bow to rise.

60. Effect of shallow water on resistance. The first effect of shallow water is to increase resistance. This is due largely to the restriction imposed on the free flow of water around the ship, resulting in the generation of higher pressures, which are made manifest by waves of greater amplitude. Another cause is that shallow water waves for a given speed are longer than deep water waves. Since the energy in a wave depends upon its amplitude and length, it follows that if in shallow water a ship's waves are longer and higher, her wave resistance is increased. As the speed is increased the difference between the shallow water resistance and deep water resistance increases reaching a maximum value which depends upon the speed-length ratio and the depth of the water. If the ship is capable of very high speed, it may be driven beyond this speed of maximum increase of resistance and enter a zone of speeds wherein the difference between shallow water resistance and deep water resistance decreases finally reaching zero. Vessels like destroyers capable of speeds corresponding to values of speed-length ratio of two or greater may actually encounter less resistance in shallow water than in deep water and consequently make higher speeds on a measured mile in shallow water than they can in the open ocean. Further investigation is necessary to explain adequately the reasons for this decrease in

resistance of a ship in shallow water when driven to extreme speeds.

61. Effect of shallow water on squat and change of trim.

The changes in resistance which occur in shallow water are accompanied by changes in level at bow and stern. The squat of a vessel underway is greater in shoal water than in deep water. In deep water a rapid change of trim begins when the speed-length ratio reaches a value of about 1.20 as given in *Art. 59*. The

shoaler the water the lower the value of $\frac{V}{\sqrt{L}}$ when this change of trim begins. Shoal water increases the stern sinkage and bow rise. It follows then that a ship at anchor drawing 30 feet forward and aft may not be able to cross a bar on which there is a depth of water of 31 feet. The greater the speed the greater the depression at the stern. When it is necessary to cross a bar or go through a channel where the depth of water is but little greater than the draft, the only safe rule to follow is to take it slowly.

A number of observations of trans-Atlantic liners going in and out of New York Harbor resulted in the formulation of the following rule by a Mr. Henry N. Babcock; that such vessels having a clearance at anchor of less than 10% of their draft would sink bodily in the channel a number of feet equal to 20% of their speed in miles per hour. According to this rule if the *Leviathan* were drawing 40 feet and attempted to go out at a speed of 20 miles per hour (17.6 knots) she would graze the bottom where the depth was 44 feet. .

62. Effect of rough water on resistance.

Apart from the reduction of speed made in foul weather to prevent racing of propellers and reduce the stresses to which the ship is subjected by reason of encountering head seas, rough water increases resistance and would slow down a ship though her engines were driven at full power. Owing to the fact that rough water is not susceptible of mathematical analysis it is impossible to state any definite propositions of its effect except that it does increase resistance. The amount depends upon the relative size of ship and waves, direction relative to the ship from which the waves are coming, relative speed of ship and waves, and the form of the ship.

In his "Speed and Power of Ships" Taylor gives the following rule: "Suppose we have two 20-knot vessels, A and B, of about the same power and such that at 22 knots A offers distinctly less resistance than B. There is little doubt that on the average A would lose less speed in rough weather than B."

SECTION C—PROPELLERS

63. Theory of self-propulsion. In the preceding sections the resistance opposing the motion of a ship through the water has been analyzed, and methods given for its computation. It now remains to discuss the means which may be applied by the ship to overcome this resistance. No discussion of towing or propulsion by sails or Floettner's rotorship is given because these methods of propulsion require agencies outside of the ship. It is obvious that if the total resistance of a ship at any definite speed is R_t , the ship must possess means of exerting an effective thrust, T , which is equal in amount to R_t and opposite in direction to the motion of the ship. In the open sea the only medium capable of exerting a reaction on the ship is the water in which it floats. Water is a liquid of little viscosity, and consequently incapable of resisting any shearing force. It follows that the only means of obtaining a reaction from the surrounding water capable of moving the ship is by driving some of this water in a direction opposite to the direction in which it is desired to move the ship. This is the fundamental principle of ship propulsion. All propelling apparatuses, regardless of appearance, are essentially pumps for imparting velocity to the water in contact with the ship in a direction opposite to that in which it is desired to move the ship.

In discussing the theory of propulsion, it is convenient to call the propelling apparatus the propeller. The discussion is general, however, not restricted to screw propellers. A discussion of this type of propelling apparatus is given in *Arts.* 66 and 67.

Any force such as R_t or T may be analyzed by the general formula based on Newton's law of motion; i.e., $f = ma$.

Let us adopt the following symbols:

R_t = total resistance of ship in pounds.

T = reaction of water acted on by propeller in pounds.

V_s = speed, relative to the surrounding water, of ship and propeller in feet per second.

V_w = speed, relative to the surrounding water, of water acted on by propeller in feet per second.

V'_w = speed, relative to ship, of water acted on by propeller in feet per second.

Q = volume of water acted upon by the propeller per second.

w = weight of one cubic foot of water in which propeller is immersed.

g = acceleration of gravity of ft.-sec. units.

W_u = useful work done by propeller in foot-pounds.

W_t = total work done by propeller in foot-pounds.

W_L = lost work done by propeller in foot-pounds.

η = efficiency of propeller.

Then
$$m = \frac{Qw}{g}$$

And since this water is assumed to have been still water prior to being acted on by the propeller and at the end of one second had a velocity of V_w , $a = V_w$

$$\therefore T = f = m\dot{a} = \frac{Qw}{g} V_w$$

By definition, work is equal to the force multiplied by the distance through which it acts. Therefore, the work done by the propeller upon the ship in one second is equal to the resistance multiplied by the speed of the ship.

Or
$$W_u = R_t V_s$$

But
$$R_t = T$$

And
$$T = \frac{Qw}{g} V_w$$

$$\therefore W_u = \frac{Qw}{g} V_s V_w$$

If we neglect friction, the lost work is that which gives the water a velocity astern, and is equal to the kinetic energy in that water

$$\begin{aligned}
W_L &= \frac{1}{2} m v^2 = \frac{1}{2} \frac{Q_w}{g} V_w^2 \\
W_t &= W_u + W_L \\
&= \frac{Q_w}{g} V_s V_w + \frac{Q_w}{2g} V_w^2 \\
&= \frac{Q_w}{g} V_w (V_s + \frac{1}{2} V_w) \\
\eta &= \frac{W_u}{W_t} = \frac{\frac{Q_w}{g} V_s V_w}{\frac{Q_w}{g} V_w (V_s + \frac{1}{2} V_w)} \\
&= \frac{V_s}{V_s + \frac{1}{2} V_w}
\end{aligned}$$

If V_w is equal to zero, T is equal to zero, and no motion will result. It follows, therefore, that V_w cannot be equal to zero and consequently that the efficiency of propulsion can never equal 100%. Further, if the total thrust, T , is not exerted in a direction parallel to the longitudinal axis of the ship but has in addition to the longitudinal component, transverse and vertical components the efficiency of propulsion will be further reduced.

If we denote the longitudinal, transverse and vertical components of the thrust by T_L , T_T and T_V .

$$\begin{aligned}
\text{Then} \quad T &= \sqrt{T_L^2 + T_T^2 + T_V^2} \\
\text{And} \quad T_L &= \sqrt{T^2 - T_T^2 - T_V^2}
\end{aligned}$$

which is the only component of thrust producing motion in the desired direction.

$$\text{And} \quad \eta = \frac{V_s}{V_s + \frac{1}{2} V_w} \frac{\sqrt{T^2 - T_T^2 - T_V^2}}{T}$$

In addition to these losses, there are other losses peculiar to the various types of propellers employed. These are discussed in the articles dealing with each of these.

64. Jet propellers; Paddle wheels. Jet propellers were carefully tried out by the British Admiralty about the middle of the last century and abandoned because of the low propulsive efficiency of the apparatus. In this system, water is admitted to the ship

through openings in the hull and flows to pumps which expel it through a jet or jets. The most efficient arrangement is to have one jet on each side at about the midlength just above the water and the inlets in the bottom of the ship giving a nearly vertical rise of the water to the pumps. If the water has a nearly vertical rise to the pumps it will take on the velocity of the ship and the inlet can be designed so as to produce no disturbance in the water which does not enter. If the jets are placed above water, the lift of the pumps is somewhat increased but that loss is less than the increase in resistance due to protruding piping and jets below water. The jets should be amidships to give short piping leads and reduce the loss due to friction in the pipes. If there are two jets and they are made to swivel, the ship can be reversed and turned by maneuvering the jets without touching the engines.

In 1881 tests were conducted for the British Admiralty on two small torpedo boats, one having twin jets and the other a single screw propeller. At equal powers the jet-propelled boat made 12.6 knots, the screw boat 17.3 knots. The propulsive efficiency of the jet-propelled boat was 25.4% ; that of the screw boat 50%.

Paddle wheels were the earliest propulsive apparatus adopted to be used with machinery and are still in use for certain types of merchant vessels. Objections to them are—

- (a) The increase of beam necessary.
- (b) Inadequate immersion of paddles due to dipping into the water at the trough of the ship's resistance wave.
- (c) Unequal action of paddles when ship is rolling.
- (d) Disturbances in water produced by paddles entering and leaving water.
- (e) Losses due to "churning" of water.

In spite of these objections paddle wheels are still used for certain vessels, principally small passenger ships engaged in coastwise or river traffic. For vessels restricted to a very shallow draft the stern paddle wheel offers a convenient though inefficient solution of the problem of propulsive apparatus. No discussion of paddle wheels is given due to their minor importance.

65. Nomenclature of screw propellers. Fig. 27 shows a three bladed propeller, true screw. Important parts are marked by name.

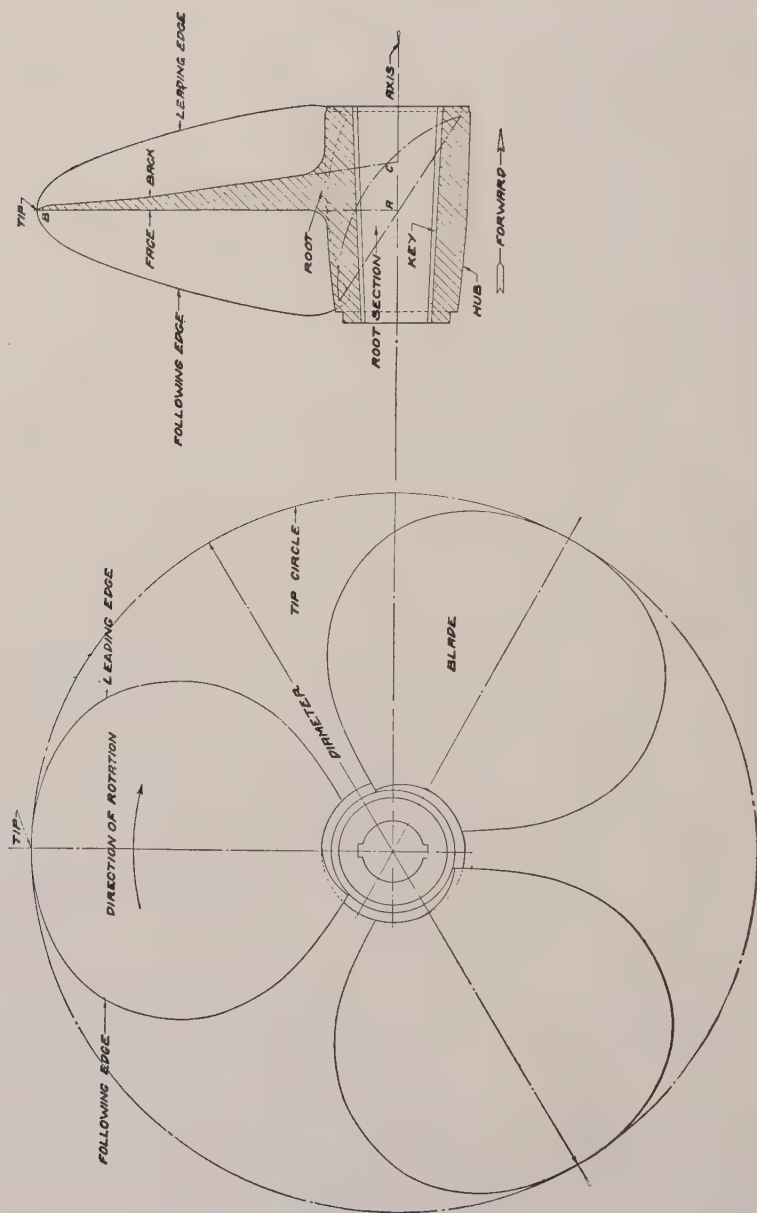


FIG. 27.—THREE BLADED PROPELLER.

This figure should be used in conjunction with the definitions given herein.

(a) A **helicoidal surface** is a surface generated by a line, set at an angle to an axis, which revolves about this axis at a constant speed and also advances along the axis at a constant speed.

(b) A **propeller blade** (true screw) is a solid having for its driving surface the portion of a helicoidal surface.

(c) A **screw propeller** consists of a number of propeller blades (usually two, three or four), spaced at equal angles about the axis, and a **hub** which forms the inner boundary of the propeller blades and provides the means of keying the shaft to the propeller.

(d) A **right handed propeller** is one which rotates clockwise as viewed from aft when driving the ship ahead. A **left handed propeller** turns counter-clockwise as viewed from aft when driving the ship ahead.

(e) The driving surface of a propeller blade when going ahead, i.e. the after surface is called the **face**.

(f) The surface opposite the face is the **back**.

(g) The **tip** of a blade is the point furthest from the axis.

(h) The **leading edge** is the edge which first cuts the water when going ahead.

(i) The **following edge** is that opposite the leading edge.

(j) The **diameter** is the diameter of the circle swept out by the tips of the blades.

(k) The **pitch** is the axial advance during one revolution assuming the propeller to be working in a fixed nut. Each point of the face may have the same pitch or the pitch may vary in several ways. In the first case the blade has **uniform pitch**. If the pitch increases from the leading edge to the following edge, it is called **axially increasing pitch**. If it increases from hub to tip, it is **radially increasing pitch**, and if it decreases from hub to tip, it is **radially decreasing pitch**. The pitch may vary axially and radially at the same time. In many calculations the **mean pitch** of a blade of varying pitch is used. The pitch referred to heretofore is the pitch of the face. Owing to the usual method of construction in which metal is added to the back as necessary for strength, every point of the back will have a different pitch. In most propeller calculations the variations in the pitch of the back

are ignored, but in the opinion of some authorities these variations affect the action of the propeller materially.

(l) The **pitch angle**, θ , for any point is the angle whose tangent is equal to the pitch at that point divided by the circumference of the circle described by that point.

$$\theta = \tan^{-1} \frac{\text{pitch}}{\text{circumference}}$$

If the pitch is uniform the pitch angle will increase from tip to hub, since the numerator of the above fraction then remains constant while the denominator constantly decreases. This angle is also called the **angle of the screw**.

(m) The **disc area** is the area of the tip circle.

(n) The **projected area** of a propeller blade is the area of the projection of the face of the blade on a plane perpendicular to the axis.

(o) The **developed area** of a propeller blade is the actual area of the helicoidal surface forming the face.

(p) Let a rectangle having the same area as the developed area of the blade be drawn tangent to blade at hub and tip. The ratio of the width of this rectangle to the diameter of the propeller is the **mean width ratio**.

(q) If the line AB is not perpendicular to the axis, the propeller has a **rake** which may be either forward or after.

(r) The **pitch ratio** of a propeller is the mean pitch divided by diameter of the tip circle. The **diameter ratio** is the reciprocal of the pitch ratio.

(s) The **blade thickness ratio** is the distance AC divided by the diameter of the tip circle.

(t) The propeller does not advance through the water as a bolt through a nut; it advances a less distance. The distance the propeller **would advance** in a unit of time if it were a bolt and the water a nut is the **speed of propeller** or **speed of screw**. The distance which the propeller **does advance** in a unit of time is the **speed of advance**. The **slip ratio** frequently called simply the **slip** is the ratio

$$\frac{\text{Speed of propeller} - \text{Speed of advance}}{\text{Speed of propeller}}$$

If the speed of advance used in this ratio is the actual speed of advance of the ship including wake effect, the resulting ratio is the **apparent slip**. If the speed of advance used is the speed without wake effect, the resulting ratio is the **true slip**.

(u) The **slip angle** is the angle between the tangent to the face and the line of advance of the blade, angle ψ of Fig. 28.



FIG. 28.—SLIP ANGLE.

(v) **Cavitation** is the name applied to a phenomenon in propeller action which occurs usually when the tip speed and average pressure on the propeller are high. It is recognized by an abrupt reduction in the thrust and efficiency, resulting in less speed of advance than might be expected with the speed of propeller. While it is accompanied by the formation of cavities in the water at both face and back of blade, the true cause of cavitation is a matter concerning which the authorities are not in agreement.

66. Theory of screw propulsion. Although screw propellers have been in use for a century, and have been studied and experimented with by numerous investigators of unquestioned standing in the engineering world, there is an unusual divergence of opinion among the authorities on almost all points having to do with propeller design. The principal reason for this is that no theory which has been advanced takes into account all of the conditions encountered in actual propeller operation. They all involve assumptions which are known to be artificial and the results deduced from them are erroneous to an extent depending upon the materiality of the differences between the assumptions made and actual conditions encountered.

The most satisfactory explanation of the action of the screw propeller is that the propeller drives aft a column of water and that the reaction from the water, which is the thrust on the propeller, is proportional to the quantity of water acted upon per unit of time and the sternward velocity imparted to it. One conception of propeller action frequently acquired by those beginning a study of

propellers, a conception which is entirely erroneous, is that the action of a propeller may be likened to a screw thread advancing in a solid medium which is capable of resisting shear. Water is incapable of resisting shear. When a pressure is exerted on water, the water yields and the thrust obtained is the reaction due to imparting a sternward velocity to the water. The best mechanical analogy to the propeller is a screw pump, which is supplied with water at its leading edge from the ocean and pumps this water astern through the surrounding water. If there were no friction, no interference with the flow of water to the propellers, if the shafts were exactly parallel to the axis of the ship, if the water were a perfect liquid, if there were no rotary velocity imparted to the water and the pressure were uniform all over the propeller, the momentum imparted to the ship would be equal to the momentum imparted to the water. This hypothesis is worthless as a working basis for propeller design, because none of the assumptions necessary are satisfied in practice and consequently the result obtained will be materially in error. Propeller designers have therefore been driven to empirical or semi-empirical formulæ and experiments with model propellers for the bases for new design.

Thus far propellers have been considered as detached from the ship being propelled. Their position relative to the ship and the underwater form of the after portion of the ship have a pronounced bearing on their action and efficiency. The water immediately surrounding the ship, due principally to the effect of friction, is moving in the same direction as the ship, as explained in *Art. 51*. The propeller instead of working in still water is, due to this effect, working in water having a motion in the same direction as the ship. The velocity of the ship through the water due to the action of the propeller is less than the speed over the ground by the amount of the wake current. This is an apparent gain.

If V_s = speed of the ship through the water

V_s' = speed of the ship over the ground

w = wake factor

Then $V_s w$ = speed of wake over the ground

And $V_s' - V_s = V_s' w$

$$V_s' = \frac{V_s}{1 - w}$$

The factor $\frac{1}{1-w}$ is called the wake gain factor.

To reduce resistance it is essential that there should be no interference with the lines of flow of the water past the ship as indicated in Fig. 29. If the stream lines close in under the stern as indicated there, the pressure generated at the bow, indicated by the crowding of the lines of flow in that region, is given up at the stern where it exerts a forward pressure. If a propeller is placed at the stern of a ship, it produces a suction drawing the water away from contact with the aftermost portions of the hull and preventing this water from exerting a pressure there to push the ship ahead. This reduction of pressure at the stern is equivalent to an increase of resistance. Or R_t , the total resistance of the self-propelled ship is greater than R'_t , the total resistance of the same ship when towed at the same speed.

$$T = R_t$$

$R_t - R'_t$ is called the **thrust deduction**.

It is usually expressed as a fraction of T .

$$\text{Let } tT = R_t - R'_t$$

$$= T - R'_t$$

$$R'_t = T(1 - t)$$

The factor $(1 - t)$ is called the **thrust deduction factor**.

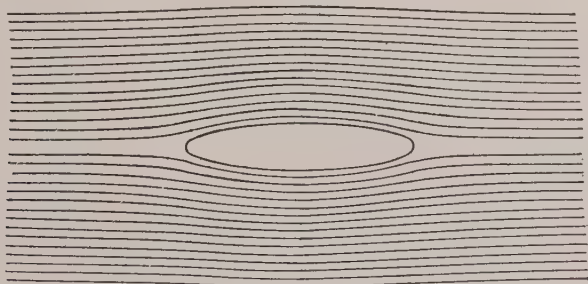


FIG. 29.—LINES OF FLOW AROUND SHIP.

If a propeller were designed to drive a ship having a tow-line resistance of R'_t through the water at a speed V_s , it would be found that if the speed through the water were adhered to, that

the speed over the ground, V'_s , would be greater than V_s and that the thrust required, T , would be greater than R'_t . The efficiency of propulsion is increased by the effect of the wake in the amount $\frac{V'_s}{V_s}$ and reduced by the propeller suction in the amount $\frac{R'_t}{T}$. The net effect is therefore the product of these two factors which product is called the **hull efficiency**.

Let $\eta_h =$ hull efficiency

$$\text{Then } \eta_h = \frac{V'_s}{V_s} \times \frac{R'_t}{T} = \frac{V_s}{V_s(1-w)} \times \frac{T(1-t)}{1} = \frac{1-t}{1-w}$$

Each of the terms of the fraction $\frac{1-t}{1-w}$ vary widely depending upon the form of the after body of the hull, the position of the propellers, their number and direction of rotation and the location of appendages, but in ships of good form with propellers located in accordance with what experience has taught to be good practice its value is usually very close to unity.

Another effect of propeller suction is to increase the trim by the stern of a self-propelled ship over that of a towed vessel. The discussion of squat and change of trim in *Arts. 59 and 61* refers to towed vessels. The sinkage at the stern due to propeller suction is small.

Due to the effect of wake, a distinction must be made between the apparent slip and the true slip of the propeller.

Let $N =$ revolutions per minute of propeller

$p =$ pitch in feet

$V_p =$ speed of propeller in feet per minute.

$S =$ true slip

$S' =$ apparent slip

Then $V_p = pN$

$$\text{And } S = \frac{V_p - V_s}{V_p}$$

$$S' = \frac{V_p - V'_s}{V_p}$$

Since $V'_s > V_s$

$$V_p - V_s > V_p - V'_s$$

$$\therefore S > S'$$

In words, the true slip is always greater than the apparent slip. A full-formed ship with a very foul bottom would have a very rapid wake current. It is possible due to this for V_s' to exceed V_p resulting in a **negative apparent slip**. This almost never occurs in practice. V_s can never equal V_p , therefore the true slip is always positive.

67. Characteristics affecting efficiency.

(a) **Number of blades.** The less the number of blades, the greater the efficiency. Two-bladed propellers are practically never used because the diameter is too great and the propeller would be too much out of balance to be used at all if one blade were lost. Three-bladed propellers are usually preferred, because they are more efficient than four-bladed propellers, unless diameter limitation makes the four-bladed propeller necessary. Propellers with more than four blades are practically never used.

(b) **Shape of blade.** The consensus of opinion is that the elliptical or oval blade gives best efficiency; the tip should be well rounded.

(c) **Thickness of blades.** Where cavitation is probable, the blades should be as thin as permissible; for slow-running propellers, thick blades give good results.

(d) **Blade area; Blade width.** These two are very closely related. Blade width is expressed in terms of mean width ratio. Some authorities have held that there is a direct relation between intensity of pressure on a propeller and cavitation. General experience has been that where cavitation is not likely blades having a mean width ratio of about 0.25 give best results. For quick running propellers where cavitation is feared a wider blade is preferable, i.e. a blade of about 0.35 mean width ratio. Wider blades are usually undesirable due to excessive friction loss.

(e) **Pitch ratio.** For pitch ratio between 1.1 and 2.0, the variation of efficiency is small. Maximum efficiency is found at pitch ratio of 1.5. The efficiency falls off rapidly for pitch ratios below 1.0.

(f) **Slip.** Greatest efficiency is obtained with a value of about 20% for the true slip. This may be increased up to 30% with

small loss of efficiency. In general, true slip should not be less than 15%.

(g) **Size of hub.** It is well to replace the inner portions of the blades where the pitch angle becomes excessive by a spherical hub. Good practice calls for a hub of about one fifth the diameter of the tip circle.

(h) **Rake.** Rake aft may be desirable to increase the clearance between blade tip and hull, but it results in increased stress in the blade. For best results there should be no rake.

(i) **Number of propellers.** The fewer the number of propellers the higher the efficiency. Limitations of propeller diameter have, however, compelled the adoption of two, three and four screws. For passenger ships, duplication of propelling apparatus is considered desirable to reduce probability of its complete breakdown. Increase in number of propellers permits use of smaller propelling units in ship.

(j) **Location of propellers.** A single propeller should be located on the centerline as far aft as practicable to reduce the thrust deduction. Regarding its vertical location there are conflicting requirements. It should be deep enough so that in still water the blades do not draw in air. But the higher it is the more benefit it gets from the wake. If it is too high it is likely to break the surface of the water in foul weather producing racing of the screw and the chance of a broken shaft. If it projects below the base line of the ship it may strike the bottom while the ship is afloat in shallow water, and in event of grounding will be seriously damaged. The net result of these requirements is that it should be given sufficient immersion so as not to break the surface of the water except in extremely bad weather, and should be high enough so that the lowest point of the tip circle is several inches above the base line of the ship.

A twin-screw ship should have its propellers, one on each side, well aft and as close to the centerline of the ship as practicable. Their vertical location should be chosen the same as for a single screw. If the clearance between propellers and hull is less than about $2\frac{1}{2}$ feet, severe vibration in the stern results.

Triple-screw ship should have one centerline propeller and two wing propellers. The disc of the center screw should clear the side

screws. The usual arrangement is with the wing screws forward of the center screws.

Quadruple-screw ship has the outboard screws forward and above the after screws to avoid interference of propeller races.

(k) **Direction of rotation.** For single-screw ships there is no preference. For the wing screws of triple-screw ships and those of twin and quadruple-screw ship the preponderance of advantage both as regards propulsive efficiency and ease of handling lies with out-turning screws. An out-turning screw is one whose blade pointing vertically up is moving outboard relative to the ship when going ahead.

Problems

66. A ship is 500 feet long. Its model is 20 feet long and weighs 2240 lbs. When the model is towed at a speed of 200 feet per minute its total resistance is found to be 5 lbs. Its skin resistance is calculated to be 3 lbs.

(1) What is the displacement of the ship (in tons) ?

(2) What speed of the ship "corresponds" to the model's speed? Give answer in knots (per hour).

(3) What is the residuary resistance of the ship at the corresponding speed (in lbs.) ?

(4) What is the total resistance of the ship if its skin resistance has been calculated to be 38,750 lbs. ?

Ans. (1) 15,625 tons; (2) 9.87 knots; (3) 31,250 lbs.; (4) 70,000 lbs.

67. Model 25' long has a resistance of 5 lbs. when towed at speed of 285 feet per minute. 2 lbs. of above due to friction. What is "corresponding speed" of a vessel 625' long and similar? What is residual resistance of the vessel at this speed?

Ans. 14.08 knots; 46,875 lbs.

68. A 20 foot model of a ship is towed in the model basin at a speed corresponding to 21 knots speed of the ship. The dynamometer registers a pull of 30 lbs., of which 16 lbs. is by calculation due to friction. The ship is 500 feet long. By calculation its frictional resistance at 21 knots is 101,250 lbs. At what speed in feet per second was the model towed? What EHP will be required to drive the ship at 21 knots?

Ans. 7.09 f.p.s.; 20,635 H.P.

69. A 20 foot model of a destroyer is towed in the basin at a speed of 15 feet per second. The dynamometer registers a pull of 40 lbs. From calculations it is known that of this amount 18 lbs. is due to friction.

The destroyer is 320 feet long. From calculations it is known that the E.H.P. required to overcome its frictional resistance at a speed corresponding to that of the model is 7,000. What is this speed in knots? What will be total E.H.P. required to drive destroyer at that speed?

Ans. 35.73 knots; 16,830 H.P.

70. A 20 foot model of the ship of Plate II is to be towed at a speed corresponding to 15 knots for the ship. What should be the speed of the model in feet per minute?

Ans. 317 f.p.m.

The normal draft of the ship is 24 feet 6 inches forward and aft. What are the displacements of ship and model when floating at normal draft?

Ans. $W = 12,700$ tons; $w = 2,318$ lbs.

What is the area of wetted surface of ship? Of model?

Ans. $S = 38,240$ sq. ft.; $s = 72.3$ sq. ft.

What is the frictional resistance of ship at 15 knots? Of model at corresponding speed? $f = 0.00892$.

Ans. $R_f = 48,430$ lbs.; $r_f = 5.2$ lbs.

The measured resistance of model at the speed corresponding to 15 knots of ship is 6.8 pounds. What are the residuary and total resistances of ship at this speed?

Ans. $R_w = 19,470$ lbs.; $R_t = 67,900$ lbs.

If the S.H.P. is twice the E.H.P., what should the S.H.P. of the main engine be?

Ans. 6,255.

CHAPTER IV

STEERING—WEIGHT—STRENGTH

SECTION A—STEERING

68. Forces due to rudder action. When the rudder on a moving ship is amidships the water flows past parallel thereto and there is no unbalanced pressure on it, but as soon as the rudder is moved the water strikes it obliquely producing a pressure due to the velocity component, U_n , which is perpendicular to the rudder; see Fig. 30.

Just as the weight of a body may be dealt with as if concen-

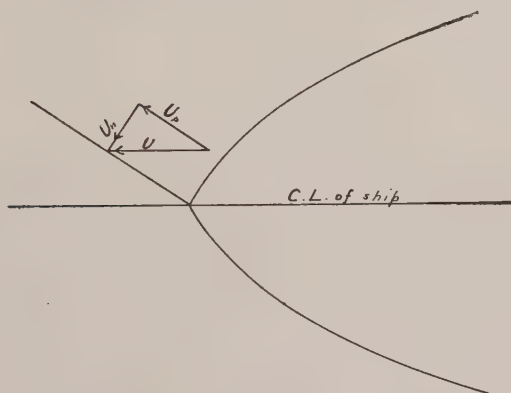


FIG. 30.—FLOW AGAINST RUDDER.

trated at the center of gravity so the pressure on a surface may be dealt with as if concentrated at the center of pressure. Fig. 31 is the waterline of a ship at the height of the center of pressure of the rudder. We have the pressure on the rudder, P , acting as indicated. To assist in understanding the various effects produced by P , we introduce in the transverse section containing the center of gravity of the ship, G , two forces equal in magnitude to P and

parallel to it, which are however opposite in direction to each other so that they have no effect. These forces are marked P_1 and P_2 . P and P_1 produce rotation of the ship. Since AC is small compared to AG we can say $AC + AG = GC$ without appreciable error. And

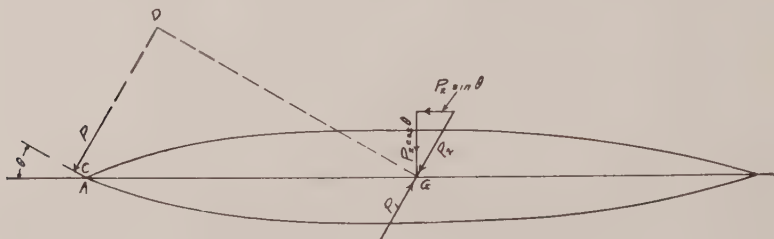


FIG. 31.—FORCES DUE TO RUDDER ACTION.

$GD = GC \cos \theta$. Therefore, the moment turning the ship is equal to $P \times GD = P \times GC \cos \theta$. **One effect of rudder action therefore is to turn the ship.** But the force P_2 yet remains to be dealt with. Let us resolve this force into two components, one, $P_2 \sin \theta$,

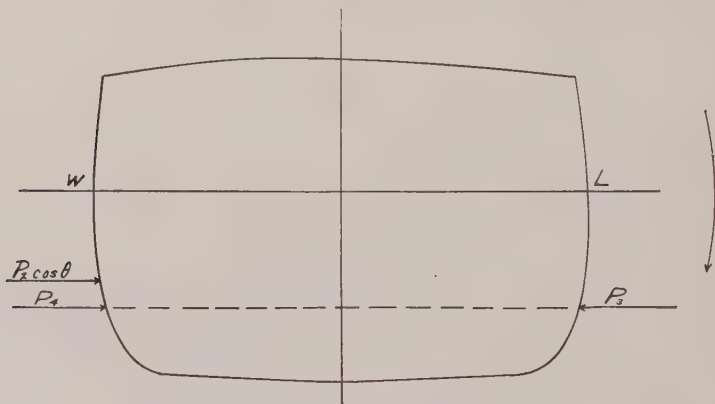


FIG. 32.—FORCES DUE TO RUDDER ACTION.

parallel, and the other, $P_2 \cos \theta$, perpendicular to the centerline of the ship. $P_2 \sin \theta$ is opposite in direction to the motion of the ship. Its effect therefore is to increase the resistance of the ship which in turn results in less speed. We have then a **second effect of rudder action, viz. to slow down the ship.** To understand the effect of $P_2 \cos \theta$ refer to Fig. 32, which is a transverse section

through the center of lateral resistance, i.e. the center of pressure of the immersed centerline plane. We have the force $P_2 \cos \theta$ acting to the right at the height of the center of pressure of the rudder. Let us now introduce two forces, P_3 and P_4 , equal in magnitude to $P_2 \cos \theta$, parallel to it and opposite in direction to each other. $P_2 \cos \theta$ and P_3 cause the ship to heel, which in the case shown and generally, is away from the center of turning, i.e. outward. Therefore, there is a **third effect of rudder action, viz. to cause the ship to heel usually outward**. A **fourth effect**, due to the force P_4 , is sidewise motion of the ship away from the center of turning, i.e. **outward drift**. There are therefore four distinct effects of rudder action, viz. turning, loss of speed, heeling and outward drift. All of these effects become manifest as soon as the rudder is put over. After the ship is turning, the outward heel and drift of the ship is augmented by centrifugal force. When a ship has little initial stability and a narrow range of stability, a dangerous heel may be produced by turning with full rudder.

69. Rudder design. In the design of rudders the following formula deduced by Joessel is employed to compute the pressure.

$$P = \frac{KAU^2 \sin \theta}{0.195 + 0.305 \sin \theta}$$

in which $K = 0.787$ if $\begin{cases} A = \text{rudder area in sq. ft.} \\ U = \text{ship's speed in ft. per sec.} \\ P = \text{total pressure on rudder in lbs.} \\ \theta = \text{rudder angle.} \end{cases}$

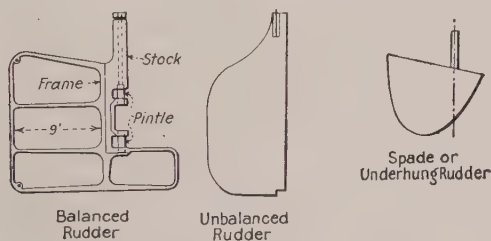


FIG. 33.—USUAL TYPES OF RUDDERS.

The area of the rudder is usually taken as 2% of the area of the immersed centerline plane. If the rudder is of the balanced type about 25% of the area is forward of the axis.

The flat part of the rudder, called the blade, must be adequately stiffened to withstand the pressure to which it is subjected when the rudder is put over against the stops, i.e. at full rudder. The size of the shaft which transmits the motion of the steering gear to the rudder, called the stock, is computed from the twisting stress set up by the pressure on the blade at full rudder. The usual types of rudders are shown in Fig. 33.

70. Turning circle. When the rudder is put over the ship begins to move in a spiral path which becomes approximately circular when she has turned at right angles to her original course. Modern steering engines permit the rudder to put over very rapidly. The diameter of the turning circle of such ships depends upon the following factors:

(a) **Size of rudder.** The pressure on the rudder and consequently the moment producing rotation of the ship vary in direct proportion to area.

(b) **Rudder angle.** The maximum pressure on the rudder occurs when the rudder angle θ is 36° . Most ships have stops to prevent the rudder angle from exceeding this amount. Smaller rudder angle gives a larger turning circle.

(c) **Loading.** A ship having heavy weights at the ends acts like a fly-wheel; it is hard to start turning, but once started is difficult to stop.

(d) **Form of underwater body.** The nearly vertical surface aft, called the deadwood, offers great resistance to turning. Where small turning circle is desired, the deadwood should be reduced.

A fair average turning circle for single screw ships of usual form with full rudder at full speed is 900 yards. The turning circle of twin screw ships can be greatly reduced by stopping or backing the inside screw.

SECTION B—WEIGHT CALCULATIONS

71. Weight groups. In the early stages of design the weight of the ship and the location of its center of gravity are estimated

from those of actual ships and the geometrical characteristics of the ship calculated on that assumption. Since the displacement is equal to the weight it becomes necessary to check the estimate of weight by computation early in the design, for if the computed weight is greater than the estimated weight, the displacement will be greater than the assumed displacement, and the ship will float deeper in the water than the assumed draft and all our former calculations are upset. The computation of the weight of the ship although simple in detail is very long and involved on account of the large number of parts entering into it and the dissimilarity of these parts as regards shape, extent and location. In view of the complexity of a ship, it is essential that there be some standard grouping of weights for purposes of comparing the weights of different ships and estimating the weight of new designs. The grouping usually used in the design of merchant ships is:

(a) **Net steel.** This group includes the weight of all steel entering into the structure of the ship, shell and deck plating, tank top, bulkheads, framing, deck structures, etc.

(b) **Wood and Outfit.** This group includes joiner work, upholstery, wood decks, sparring, ceiling, smith work, rigging and gear, anchors and chains, iron and steel castings, cement and tile work, plumber work, donkey boiler, winches, refrigerating machinery, steering gear, windlass and capstan, bilge and ballast piping, electric generator, switchboard and electric fixtures, watertight doors, boats and davits, paint, deck stores, life buoys, etc.

(c) **Machinery.** This group includes boilers, engines and auxiliary machinery, shafting and bearings, propellers, machinery spares, etc.

(d) **Deadweight.** This group is sometimes divided into (1) **fuel and stores** and (2) **paying deadweight**. The latter is that for which the ship is built, freight; the former includes food, fuel and fresh water.

(e) **Margin.** In addition to these known weights a margin usually taken as equivalent to twice the tons per inch at the load draft is allowed for unforeseen weights that enter into every ship. This margin amounts to assigning weights such that the draft will be two inches less than designed.

72. Methods employed. There is a wide diversity in the methods employed to compute the light weight of the ship, which subtracted from the displacement at load draft gives the dead-weight. Certain weights such as joiner work, upholstery, rigging, plumber work, paint, etc., are estimated from the known weights of similar ships. Some weights such as anchors and chains are obtained directly from the rules under which the ship is to be built. Weights of certain articles of equipment may be obtained from the makers. These articles include winches, electric generator, refrigerating machinery, steering and anchor handling gear, boats and davits. The weight of machinery is obtained from its horsepower. Certain weights such as stem and sternpost are obtained by straightforward calculation. Weight of transverse framing is obtained by calculating the weight of type frames and plotting weight against longitudinal position in ship, then drawing a curve through the plotted points, from which the weight of any frame and total weight of all frames may be estimated. Weight of bulkheads, decks and shell plating, is estimated from a computation of their areas. The computation of the weight of a ship is a long and complex process which taxes the ingenuity in many particulars.

SECTION C—STRENGTH CALCULATIONS

73. Structural stresses. In studying the strength of a ship, two classes of stresses must be considered **(a) structural stresses**, i.e. stresses resisted by entire ship structure and **(b) local stresses**. In the study of structural stresses the formula used is that for calculating the stress in any beam or girder, viz. $f = \frac{My}{I}$.

where f = stress intensity (tension or compression)

M = bending moment at any section

I = moment of inertia of section

y = distance of point from line of no stress (neutral axis)

At any section M and I are constant for that section. Therefore in any section the severest stresses occur in those structures most remote from the neutral axis, i.e. the deck and bottom plating. M

and I vary from point to point along the length of the ship. The stress will therefore be a maximum in the deck or bottom plating of that section where $\frac{M}{I}$ is a maximum. This is usually at about the midlength of the ship.

74. Method of computing stresses in ship girder. Fig. 34 is a series of curves used in the computation of stresses in the ship girder. These curves are all drawn on the length of the ship as a

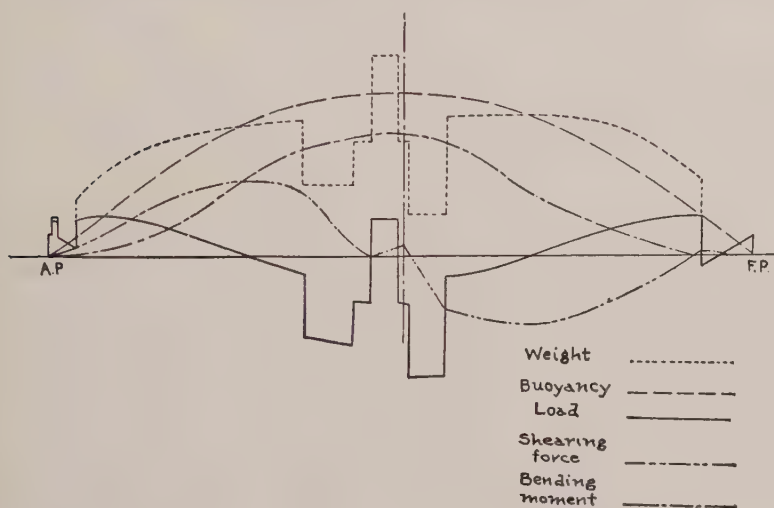


FIG. 34.—STRENGTH CURVES FOR SHIP.

base. A curve is drawn so that the ordinate at any point shows the upward force of buoyancy at that point. Another curve showing the load at each point in the length of the ship is drawn. At certain places along the ship's length the weight exceeds the buoyancy while at others the reverse condition obtains because of course, **the total weight equals the total buoyancy**. The difference between the weight and the buoyancy at any point leaves a free force which **tends** to move that section of the ship up or down alongside adjacent sections. Such a force is known as a **shearing force**; it tends to shear the ship girder at that point just as we shear an angle bar in the plate shop. In properly designed ships, the shear-

ing force results only in a **tendency** for the section to move; no actual deflection occurs due to the continuity of the ship structure. This inequality between weight and buoyancy along the ship also results in a tendency to **bend** the ship. In other words it produces a **bending moment**. The curve of bending moment is obtained from the curve of shearing forces by integration, an involved mathematical process. If the weights at the ends exceed the buoyancy there and the deficiency of buoyancy at the ends is compensated by excess buoyancy amidship, the ship tends to bend so that the bottom becomes a curve, concave down. In such a case the ship is said to have a tendency to **hog** and the deflection of the ends is known as the **amount of hog**. If the reverse condition obtains and the bottom tends to curve concave up, the tendency is known as **sagging** and the deflection of the **middle** the **amount of sag**.

The buoyancy and consequently the bending moment at any section depends upon the height of the water at that section. Computations of strength are usually made only for load draft because when fully laden the ship is subjected to the severest stresses. Three calculations at load displacement are made, (a) still water (b) in waves of length equal to that of ship and height one twentieth of length with crest at midlength, and (c) in waves of same dimensions with trough at midlength. The condition described in (b) is called **hogging condition** because under these circumstances the tendency to hogging is greatest; that described in (c) is called **sagging condition** because then tendency to sagging is maximum. A ship among waves passes from hogging condition to sagging condition every wave length. The forces induced result only in tendencies to bend or shear, the actual deflections are small in steel ships.

75. Stresses in deck and bottom. When a ship has a tendency to hog, the deck plating is in tension and the bottom plating is in compression. When she has a tendency to sag, the reverse is true. When she is among waves, she changes from one condition to the other every time a wave goes by. The deck and bottom plating are therefore subject to very rapid reversal of stresses of considerable magnitude and must be strong and rigid to prevent

any appreciable deflection. Where the deck plating is cut as for cargo hatches and smoke stacks, doubling plates or other compensation for the material removed must be provided.

76. Stresses in side plating. The side plating is rigidly secured to the bottom and deck plating, but while the deck and bottom plating have a practically uniform stress all the way across any section, the stress in the side plating is uniformly varying. In hogging condition the plating near the top is in tension which decreases becoming zero at the neutral axis. Below the neutral axis the side plating is in compression increasing to the turn of the bilge. This condition of stress is termed longitudinal shear because the fibers in the side plating tend to move on each other. This longitudinal shear is a maximum at the quarter length in the region of the neutral axis and is usually taken care of by providing additional rivet area in this vicinity.

77. Stresses in sheer and bilge strakes and deck stringers. The top row of side plating is called the sheer strake, the strongly curved row of plating at the turn of the bilge, the bilge strake and the strakes of deck plating next to the side plating, the deck stringers. It is the function of these strakes to transmit the tensile stresses of the deck and bottom to the side plating. They connect to the deck and bottom at a sharp angle with resultant intensification of stress at lines of connection. They furthermore transform the tensile stresses of the deck and bottom to longitudinal shear in the sides. They are therefore most important structural members and being subject to intensified stresses are usually heavier than the other shell plating.

78. Requirements for strength members. The size of strength members should be proportioned to the stress carried. The variation of bending moment in the ship girder, as illustrated in Fig. 34, permits progressive reduction in the size of the strength members from the middle towards each end. Structural steel comes in shapes of constant dimensions throughout the bar. Reduction in size of strength members must therefore be made in steps. It is essential that such steps be gradual.

Any sudden discontinuity in the strength of the structure may

result in failure at that point. An example of discontinuity which had to be corrected is that of a tanker which had a centerline bulkhead in way of the tanks. This bulkhead took part of the stresses which in ships not so fitted is taken by the side plating. It terminated forward at the transverse bulkhead separating the cargo tanks from the hold and crew's quarters and aft at the transverse bulkhead forward of the machinery compartment. It was found necessary to fit large triangular plates at top and bottom at each end of this centerline bulkhead to provide for tapering the stresses carried and to provide a means of transmitting its stress to the bottom and deck structure.

79. Transverse and local stresses. The beam of a ship is so much less than its length and the transverse structural members are so much more numerous than the longitudinal structural members that the transverse stresses due principally to external water pressure are usually small compared to the longitudinal stresses. When a ship is rolling in a seaway, there is a tendency to wrack the structure. Some conditions of loading may put a torsional stress on the structure but in well-designed ships these stresses are seldom serious in amount. When a ship is in dry dock supported only by blocking under its bottom the transverse bulkheads may come under excessive stresses due to longitudinal shear. Evidences of insufficient rivet area may be detected in the vicinity of the neutral axis of the bulkhead.

The above discussion applies to stresses affecting the entire ship structure. Severe stresses which are entirely local may occur under heavy weights; or at localities subject to shocks, such as gun foundations.

CHAPTER V

CLASS AND TONNAGE

SECTION A—CLASSIFICATION

80. Classification societies—Names and functions. The first classification society to be established was Lloyd's Register of Shipping which dates from 1760 although its activities as a classification organization did not begin until somewhat later. Its earliest function was marine insurance, an activity which is still continued although entirely apart from its classification activities. Other organizations, which are largely patterned after Lloyd's, are the American Bureau of Shipping, British Corporation Registry, Germanischer Lloyd's and Registro Nazionale Italiano. Except for Great Britain every maritime nation has one such organization which performs similar functions for the ships built in that nation. These functions are:

(a) **Publication of a "register."** This register contains the name, classification, place and date of construction, present owner, tonnages, type of machinery, and other pertinent information of all ships included in that register.

(b) **Publication of instructions for constructing ships.** These publications are the shipbuilders' Bible containing as they do definite rules by which the dimensions of all structural members are determined.

(c) **Inspection of ships under construction.** This is to insure good workmanship and full and complete conformity with the "rules." The assignment of classification by a society is a guarantee of the structural adequacy of the ship either for any trade or a particular service. The society can only be reasonably assured that the builder is complying with the rules of construction by inspection during this time.

(d) **Inspection of material.** To obtain classification the struc-

tural material entering the ship must be passed by an inspector in the employ of the society. If the highest classification is desired, the equipment must be similarly inspected. This inspection is necessary to insure the adequacy of structure and equipment for the trade in which the ship will operate.

(e) Survey of ships. Ships built under survey are in general required to have additional surveys every four years. In event of stranding, collision or other accident, a surveyor in the employ of the society makes an examination to make sure that the damage is made good. Ships not built under survey may be surveyed at any time and assigned classification.

81. Nature of rules. Each classification society has one or more volumes of rules for the construction of ships to class under its requirements. The rules of the American Bureau of Shipping are typical and will be used as an illustration. The very highest classification assigned a ship is + A.1.®. The symbol + signifies that the vessel was inspected during construction and that the material and workmanship are in strict accordance with the rules of the Bureau. The symbol ® signifies that the equipment is in accordance with the rules. When such is not the case a dash — is used in place of ®, thus: + A.1. —. The symbol A.1. means a first class ship suitable as far as strength is concerned for trade in any part of the world. The words "With Freeboard" after the classification symbols indicate that the vessel may engage in trade in any part of the world provided that the minimum freeboard for such vessel will be assigned by the Bureau. Vessels built and classed only for a particular trade have designating words after the classification symbol, such as: "River Service," "New York-Boston," etc.

Similarly classification for propelling machinery indicated by symbol + A.M.S. and for refrigerating machinery indicated by + R.M.C. will be assigned where these are in accordance with the rules of the Bureau and subject to inspection during construction. When the latter requirement is not complied with the symbol + is omitted.

The rules themselves are similar. They give certain empirical formulas for the computation of various "numbers." Using these "numbers" and certain dimensions of the ship, one can pick from

tables given therein the dimensions of the various structural members, their spacing and the requirements of various articles of equipment. It is a purely "rule of thumb" process. The formulas themselves have certain theoretical foundation but their principal justification lies in the fact that ships built in accordance with them have been satisfactory and successful ships. It is not necessary that the operating officer should have a detailed acquaintance with these rules, but to the shipbuilder this is as essential as a knowledge of the multiplication table.

SECTION B—TONNAGE

82. Sources of rules for tonnage measurement. Whereas conformity with the rules of a classification society to obtain a certain class rating is optional with the owner, measurement of tonnage is required by statute. Each of the maritime nations has enacted laws stating the methods of measuring merchant ships and computing their tonnage. Formerly there were considerable differences between the various nations but during the last fifty years, by means of international conferences, the rules for tonnage measurement of the various nations have been brought into substantial agreement, so that now the tonnage certificate of a ship of U.S. registry is accepted in the ports of the following countries: Great Britain, Belgium, Denmark, Italy, Sweden, Norway, Spain, the Netherlands, Russia, Finland, Portugal, Japan, France, Germany, and Free City of Danzig, and similarly the certificates of ships of these nations are accepted in the United States and any other of the countries listed above. This reciprocal acceptance of another nation's tonnage certificate, brought about by obtaining agreement in the methods of measurement and computation, is a matter of great convenience to ship owners and operators.

The rules for the tonnage measurement of ships of U.S. registry are formulated by the Commissioner of Navigation (an official under the Secretary of Commerce), under the authority of statutes of Congress. They are contained in a publication entitled "Measurement of Vessels" issued by the United States Department of Commerce, Bureau of Navigation.

Theoretically the measurements for tonnage computations are taken from the ship. Actually they are taken from the drawings of the ship and certain measurements of the actual ship taken as a check on the accuracy and veracity of the plans.

83. Gross tonnage. A measurement ton is 100 cubic feet.

The intent of the rules for tonnage measurement is to determine the cubical contents inside the hull. Due to developments in shipbuilding and tricks of language, this intent frequently lacks a great deal of fulfillment in the tonnage computation. The rules are now—just rules—to be carefully studied by the shipbuilder, owner and operator so that he can build a ship of maximum cargo carrying capacity on the minimum registered tonnage. Because the earnings of the ship depend primarily on her paying deadweight while wharfage, pilotage and dockage and numerous other dues and taxes depend upon the registered tonnage.

Registered tonnage is net tonnage, i.e. gross tonnage minus certain permissible deductions.

In measuring the internal contents of the hull of a ship, the spaces are classified as **included** or **exempted**. An **included** space is one whose volume is measured and included in summing up the volumes from which the gross tonnage is computed. An **exempted** space may or may not be required to be measured but in either case its volume is **not** included in volume used to compute the gross tonnage.

The gross tonnage consists of (a) the underdeck tonnage, (b) 'tween deck tonnage, (c) tonnage of certain spaces above upper deck, (d) "excess of hatchways."

(a) **Underdeck tonnage.** The underdeck tonnage is the tonnage of all included spaces below the **tonnage deck** which is the upper deck of the hull except in vessels having three or more decks to the hull in which case it is the second deck from below. The Regulations for the Measurement of Vessels require the measurement of breadth and depth of hold at a certain number of equally spaced transverse sections. The number of transverse sections required depends upon the **tonnage length** of the ship. At each transverse section the depth of the hold is measured making certain specified allowances if the beams have a camber

or pitch and the tank top has pitch or dead rise. If the tonnage depth of the midship section does not exceed 16 feet, four breadths at equal intervals between the top and bottom of each section are measured and the area of each section computed by Simpson's first rule. If the tonnage depth exceeds 16 feet the depth of each section is divided into six equal spaces for measurement of breadths. The breadths of sections are taken from the surface of the ceiling or battens (average thickness) usually fitted in cargo holds. The areas of transverse sections so obtained are then put through Simpson's first rule and the contents of the space under the tonnage deck computed.

(b) **'Tween deck tonnage.** This is the tonnage of the space between the tonnage deck and upper deck. The volume of this space is determined by first computing the area of a plane at the midheight of the 'tween deck space by Simpson's First Rule, and multiplying this area by the mean height.

(c) **Enclosed spaces above upper deck.** Some of these spaces are included in computing the gross tonnage and some are not. Whether a space is exempted or not depends entirely upon the provisions of the regulations and whether it satisfies certain arbitrary requirements. No simple rule can be given to cover what spaces are exempted and what are included. When a space is included, its volume is computed in the same way as that of the 'tween deck spaces.

(d) **"Excess of hatchways."** Realizing that high coamings around cargo hatches gave increased protection to the ship in foul weather, the authorities in framing early regulations for tonnage measurement allowed the volume of hatchways within the coaming to be excluded in computing the gross tonnage. The regulations now limit this exemption to $\frac{1}{2}\%$ of gross tonnage. The tonnage of hatchways in excess of $\frac{1}{2}\%$ of the gross tonnage is the "excess of hatchways."

The spaces given below are the only ones which in general are exemptible in measurement of gross tonnage. Whether a particular space is actually exempted depends upon its compliance with certain arbitrary provisions of the regulations. Peak and other tanks for water ballast, open forecastle, open bridge, open poop, anchor gear, steering, donkey engine and boiler spaces, light and air

trunks, wheelhouse, galley, condenser, water-closets, domes, skylights, companions except portions used for smoking rooms, cabins for passengers. To obtain exemption, all of these spaces except peak tanks must be on or above the upper deck to the hull.

84. Net tonnage; Suez and Panama Canal tonnage. A **deducted space** is one whose tonnage is subtracted from the gross tonnage to obtain the **net** or **registered tonnage** of a ship. The original principle which governed in the selection of deducted spaces was that the spaces required for quartering the crew and officers and working the ship and therefore not available for the carriage of cargo deducted from the gross contents of the hull gave the net useful space within the ship which was a measure of its earning power, and therefore a proper figure on which to base its wharfage, pilotage and other dues. This is interesting historically but has little relation to present conditions. The rules for deductible spaces are just rules to be studied by builder and operator so as to get as large an allowance as possible but are not logical. They are simply legal. There are given a list of spaces which may be deducted from the gross tonnage in computing the net registered tonnage. In each case the rules specify certain requirements which must be fulfilled to entitle the ship to this deduction. No space may be deducted unless it was included in computing the gross tonnage. These spaces are crew spaces, hospital spaces, washrooms and bathrooms, master's cabin, any space used exclusively for the working of the helm, capstan and anchor gear or for keeping charts, signals, lamps and other instruments of navigation and boatswain's stores, chain locker, space occupied by donkey engine and boiler, sail storage, propelling machinery.

The largest single deduction is for the propelling machinery. This deduction is governed by the following rules. In the case of screw propelled vessels, the permissible deduction is 32% of the gross tonnage if the actual tonnage of the machinery space lies between 13% and 20% of the gross tonnage. If the actual tonnage of such space is less than 13% or more than 20%, the permissible deduction is one and three-fourths times this tonnage. In the case of paddle wheel vessels the permissible deduction is 37% when the actual tonnage of machinery space is between 20%

and 30% of the gross tonnage, and one and one half times the actual tonnage when such is outside these limits. If necessary to bring the tonnage of the machinery space up to the minimum for the fixed deduction, i.e. 13% for screw steamers and 20% for paddle wheel boats, a portion of the light and air trunks above these spaces, which are ordinarily not included in the gross tonnage, may be added into the gross and then included in the actual tonnage of the machinery space to secure the benefit of the 32% or 37% deduction. It is apparent that a ship designer can juggle the extent of the machinery space to get the benefit of the maximum deduction with the least actual space taken for propelling machinery. This is one of the "tricks of the trade."

The rules for computing the tonnage of ships for assessment of tolls for passage through the Suez and Panama Canals are slightly different from those given above for computing the registered tonnage. They are included in the publication issued by the U.S. Department of Commerce, Bureau of Navigation, entitled "Measurement of Vessels." The differences are relatively minor and will not be gone into here. A ship wishing to transit either of these canals must present a tonnage certificate prepared in accordance with instructions of the Universal Maritime Canal Company of Suez, or the Governor of the Panama Canal respectively. Such certificates are prepared by customs officers for ships of U. S. registry on the application of the ship owner.

CHAPTER VI

SHIP DESIGN AND CONSTRUCTION

SECTION A—PROCEDURE IN SHIP DESIGN

85. Initiation of design. The problem given to the ship designer on which to bring out a ship is stated in a variety of ways. The information usually given, the characteristics in which the operator has a vital interest are (a) paying deadweight or its equivalent, i.e. gallons of oil, bags of sugar, bunches of bananas, etc., (b) speed, or information from which speed can be obtained such as time for a certain run, (c) steaming radius without refueling, (d) if passenger ship, number of passengers, (e) limiting considerations of length, beam or draft where such limitations exist due to canals, turning basins, bars, etc., (f) sometimes type of machinery or boilers and kind of fuel is specified.

86. Design personnel. The official in charge of the design of a ship and responsible to the owners that a ship filling their requirements is produced is commonly termed the "Naval Architect" or "Owner's Representative." He supervises and co-ordinates the work of the various naval architects, engineers and draftsmen working on the design to produce a balanced design which fits the owner's requirements. Frequently, he passes on the working plans prepared by the shipbuilder and inspects the work during the period of construction. In fact, he has a certain responsibility for the ship as long as she is operating.

87. Estimate of displacement. The first thing to decide upon is the light weight of the ship. This plus the given deadweight gives the load displacement. From this last the principal dimensions are obtained. The best method of estimating the light weight and load displacement is by comparison with a similar ship of about the same deadweight tonnage. The tonnage in each weight

group (see *Art. 71*) comprising the light weight is carefully estimated from the known weight of this group in the type ship. The margin is added to the sum of weights so obtained to give the estimated light weight of the new design. The considerations which determine the differences in weight between groups of the new design and type ship are many and complex and depend somewhat on experience.

In general the cost of a ship depends directly upon the weight of material worked into it, i.e. the light weight of the ship. It is therefore desirable to keep this weight as low as possible consistent with safety and a properly balanced design.

88. Estimate of principal dimensions. Having determined the displacement it remains to determine the principal dimensions, length, beam, draft and freeboard. Theoretically there is an infinite number of solutions; an infinite number of ships may be defined which will have the required displacement. Actually, the principal dimensions are limited by other considerations to a narrow range. The principal considerations affecting the choice of these dimensions are as follows:

(a) Length (L). Great length is undesirable because the frictional resistance (which for 90% of merchant ships is 90% of the total resistance) increases with length. This has a direct bearing on operating costs. Further the longer the ship the greater the maximum stresses she is subject to and the greater the hull weight required to prevent excessive stress intensities, and consequently the greater the light weight and initial cost of ship. The ship should therefore be as short as dictates of good practice permit.

(b) Beam (B). The beam has the greatest effect on stability, for $BM = \frac{I}{V}$ and I varies as B^3 . Contrary to the notions of many, the beam has very little effect on resistance. Model tank experiments have proven that ratio of beam to draft may be varied through a wide range without producing a material change in resistance. Frequently the beam is fixed by considerations outside the ship such as canal locks and channels.

(c) Draft (D). Deep draft is desirable for good sea speed. Further with given freeboard deeper draft results in greater hull

depth and consequently increased longitudinal strength. Usually the draft is fixed by the depth of water at certain harbors into which the ship is designed to go.

(d) **Freeboard (F).** The range of stability and reserve of buoyancy depend upon the freeboard. Further, the freeboard is the one characteristic of a ship affecting its stability characteristics which is capable of easy measurement. It is therefore of the utmost importance in merchant ship design. The rules for computing the required freeboard used in this country and Great Britain are promulgated by the British Board of Trade. These rules are rather involved, and being a matter which concerns the designer rather than the operating officer, will not be given herein. For ships of British registry the freeboard computed by the rules is a legal requirement. For ships of American registry it is not a legal requirement but is a requirement to obtain classification under the American Bureau. It is therefore the basis for computing freeboard for most ships of the world. From a technical point of view, it is apparent that for a given draft, the hull depth and consequently the longitudinal strength are increased by increased freeboard.

89. Plans and specifications prepared by designer. Having decided upon the load displacement and principal dimensions of the new design, the designer proceeds to prepare certain plans and specifications from which the shipbuilder can construct the ship so that when completed it will be the ship the owner wants. The plans prepared by the designer are:

(a) Line Drawing similar to Plate I. After the line drawing is made and faired, the half breadths of each waterline at each station, the heights of each buttock at each station and other measurements necessary for its reproduction are made and the results made up into a table known as the "Table of Offsets." From these offsets calculations for displacement and stability are made by the various rules of mensuration as explained in Chapters I and II. From these calculations the Displacement and Other Curves (like Plate II) and Cross Curves of Stability (like Fig. 17) are drawn.

(b) Midship and other sections, showing structural details, such

as thickness of plates, types of shapes and design of joints and connections for frames in parallel middle body and certain type frames along the ship's length, see Plate IV (pages 132 and 133).

(c) General arrangement plans, showing methods of access and location of various spaces.

(d) Machinery arrangement plans.

In addition, the designer prepares detail specifications stating the characteristics required of the ship, the rules under which she is to classify and the work to be done and equipment to be furnished by the builder.

SECTION B—PROCEDURE IN SHIP CONSTRUCTION

90. Building ways. In this country practically all ships are built on the ground. This requires the preparation of building ways. Fig. 35 is a general view of a building ways showing the weight handling equipment. It is usual to build ships with their fore and aft line perpendicular to the shore line on account of the cost of waterfront land, although on the Great Lakes ships are frequently built broadside to the water and launched sideways. In either case the land usually has to be piled on account of its low bearing power and the piling is sawed off to give a predetermined declivity which for ships built endwise is about $\frac{3}{8}$ to $\frac{3}{4}$ inch to the foot. The piling is particularly important under the keel blocks which carry the weight of the ship during erection and under the area where the ground ways will be since these carry the weight of the ship during the launching. The whole is usually covered by a working platform. Shoring to support the ship upright and staging to facilitate work are erected around the ship giving it the usual caged-in appearance.

91. Preliminary work in drafting room and mold loft. The preparation of the half model in wood in the drafting room and the laying off and fairing of the lines on the mold loft floor may proceed simultaneously. The model is usually made to scale of $\frac{1}{4}$ inch = 1 foot. On it are drawn first the frame lines and then the edges of the shell plating and the location of joints (butts)

between the individual plates in the rows (strakes) of shell plating. After this other structural details are added such as the intersection of transverse bulkheads and decks with side, the location of longitudinals, bilge keels and outboard fittings and the location of airports. The lengths of many of the structural members are taken from the model in preparing the order to the steel mills for the material. Information for preparing the order



FIG. 35.—BUILDING WAYS.

for the shell plating is usually taken from the shell expansion plan, which is a plan showing the developed shape and size of each plate. Material is always ordered slightly larger than the measured dimension on the model, the amount of this allowance is determined mainly by practice.

In addition to the model, plans for the stem and sternpost, deck houses and detail working plans are gone ahead with in the drafting room.

The mold loft is a large room without pillars or obstructions,

well lighted and having a smooth floor free from nails. The floor serves as a drawing board for laying off the ship to full size. Recent practice is to make the longitudinal scale about one fourth the full size. This is necessary in long ships like the *Leviathan* which are longer than most buildings on shore. The ship is laid off on the fairing stations from information given in the table of offsets and line drawing. After the line drawing has been laid down on the mold loft floor and faired, i.e. the intersections made to check in all three views, the frames are laid off in the half breadth plan where they appear as straight lines. The true shape of the frames is then laid off in the body plan by measuring the half breadth at each waterline in the half breadth plan and drawing a curve through the points so obtained. Since the half breadths of the frames are obtained from faired lines they should come out as fair curves. If when drawn in on the body plan a frame shows points of unfairness, the lines must be adjusted to make it come fair. After the frames are laid off and faired they are scribed in the mold loft floor because they are used in fabricating the material for constructing the ship.

92. Preparation of material for erection. Templates showing the true shape of the outline of all structural members of the ship are made from dimensions obtained on the mold loft floor. As an illustration the steps in the process of preparing a frame for erection are given. The template is taken to what is known as a bending slab, see Fig. 36, and its outline marked on it. A bar of sufficient length is heated in a furnace which is located adjacent to the bending slab. When the bar reaches a bright red heat it is hauled out, bent to conform to the curvature marked on the bending slab and secured in place to cool. Being bent hot it retains its curvature on cooling. The bar then goes to the laying out table where the rivet holes are laid out and marked, and then to the punch for punching the rivet holes. It is then ready to be taken to the building ways for erection in the ship.

93. Sequence of operations in erection. On the working platform of the building ways, a scaffolding conforming to the shape of the ship's bottom is prepared. The flat keel plate is first laid

on the keel blocks and the individual plates are riveted together. This is the "laying of the keel." The bottom plating is then laid out on this temporary scaffolding to the turn of the bilge. The framing, both transverse and longitudinal within the double bottom space is erected on the outer bottom, see Fig. 37, and on top of the framing, the inner bottom plating, also called the tank top, is laid. The main transverse bulkheads are then set up on the inner bottom and temporarily shored in place. A few frames



FIG. 36.—BENDING SLAB.

with the deck beams for the bulkhead deck are also set up and shored in place. The shell plating is then bolted to the frames and bulkheads which have been temporarily shored in place, after which the remaining frames and bulkheads are set up and bolted to the shell plating. By the time the shell plating is up to the bulkhead deck the stem and sternpost should be ready and set up and the shell plating tied in to them. The bulkhead deck is then laid on the deck beams and the bulkheads standing on it and certain frames with deck beams for the deck next higher are set up on it. The shell plating above the bulkhead deck is bolted to these bulkheads and frames and the remaining frames are secured

to the shell. This procedure is continued until the entire structure is erected. Structural members are first bolted in place, the riveting is not started until the preliminary erection has reached such



FIG. 37.—EARLIEST STAGE IN ERECTION OF SHIP.

a stage that it can be accurately determined that all structural members are in their proper location and have the proper set. The foregoing is the usual procedure; it is subject to some modification in different localities and for ships of unusual form.

94. Inspection during construction. During construction, ships are subject to inspection by a representative of the owner to make sure that the contract plans and specifications are being complied with and to pass upon the working plans. This representative is frequently the naval architect who prepared the design. He may have office space at the shipbuilders and have representatives in constant attendance. In addition, if the ship is being built to a certain class, the classification society requires

the right to pass upon all important plans, to forbid the use of any material which does not comply with its minimum requirements, to reject work which does not measure up to the society's standard of workmanship, and the performance of certain tests on the structure in the presence of a surveyor. The requirements of the American Bureau of Shipping in these regards will be given in the later chapters in the discussion of the structural features of the ship. These requirements differ only in minor particulars from those of all classification societies.

95. Launching and completion. Ships built on ways require moving to the water. This operation is launching and the ways are usually so constructed that ship can be slid from them into the water. The state of completion at which the ship is launched depends upon a variety of things such as the permissible launching weight, weight handling facilities on ways and at wet basin where ship will be finished if launched and work in prospect. Launching calculations are very involved; the stability of the ship during the launch and stresses set up in the structure must be carefully investigated.

While on the ways the ship is supported on the keel blocks and kept in an upright position by numerous shores on each side. For launching, tracks at a predetermined slope are built running down under the water. For ships built endwise there are two tracks and the space between them is about one third the ship's beam. For ships built broadside to the water the tracks are more numerous. These tracks are the ground ways. Other tracks, the sliding ways, are prepared to slide on the ground ways. Between the sliding ways and ship's bottom a cradle conforming to the shape of the bottom is built. Grease is placed on the ground ways to reduce friction. On the day of the launching the ship is lifted off the keel blocks by driving wedges between the sliding ways and the cradle. In preparing for the launch the in-shore end of the sliding ways is bolted to the ground ways. When the weight of the ship has been shifted to the launching cradle, the keel blocks are removed and the in-shore end of the sliding ways freed by sawing between the bolts and the ship. Powerful hydraulic jacks should be in position to start the ship in case she does not start herself. The

cradle, ship and sliding ways move down the ground ways together. After the ship is in the water the cradle and sliding ways are freed.

After the launch, the ship is moored in a wet basin where the work remaining is completed and the ship is fitted out for service. When this is essentially completed the ship is taken out and trials are run, upon the satisfactory completion of which the ship is delivered to the owners.

CHAPTER VII

HULL PROPER

SECTION A—MATERIALS AND JOINTS

96. Structure materials. The hull structure of ships has in the past been built of wood, wrought iron, steel and concrete. Wood was the earliest shipbuilding material. It is fairly abundant; the source of supply is widespread; it is easy to work. Large ships cannot be built of wood because connections between the individual pieces cannot be devised to develop the full strength of the material. Rigid connections between members of wooden hulled vessels are practically impossible so that such vessels unless small give evidence of working and frequently have excessive hog or sag (5 or 6 feet). Wood is not uniform in structure or strength; it has a plane (parallel to the grain) of practically no strength; it is subject to organic decay and injury by worms, insects and marine worms (teredoes); for equal strength it is heavier than steel; it is combustible.

Before the invention of the Bessemer and open hearth processes of steel making, very little steel was produced and that little used principally for cutlery. The production of wrought iron was cheaper and larger in amount. Wrought iron was therefore the first metal to be used for shipbuilding. Iron ships are not built any more because steel costs less and is stronger and more uniform, although more subject to corrosion.

By far the vast majority of ships are built of steel. Steel can be produced which is practically uniform in strength, structure and composition; it is fairly cheap; it can be easily worked into shapes to give the greatest strength for weight; joints can be made to develop practically the full strength of the pieces joined. The principal disadvantage of steel is its susceptibility to corrosion. Deterioration from this cause is reduced by painting.

Reinforced concrete was used during the World War when the demand for ships was well-nigh insatiable. Very few, if any, have been built since. In these the tensile strength is provided by the steel reinforcing rods. The principal objections to this method of construction are the excessive hull weight and consequently

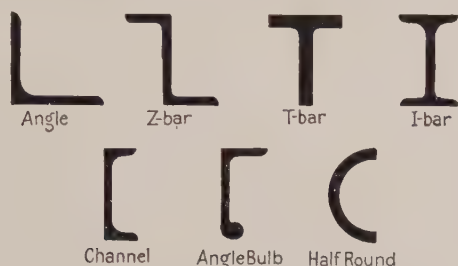


FIG. 38.—SHIPBUILDING SHAPES.

reduced paying deadweight on a given displacement and susceptibility to local injury.

Steel used for shipbuilding is made by the open hearth process and is subject to inspection and test at the works of the manufacturer by a representative of the classification society. The



FIG. 39.—COMMON FORMS OF RIVETS.

rules of the classification societies specify the characteristics which must be possessed by steels for ships built to class in them and the nature of tests conducted by their surveyors.

Shipbuilding steel comes in the following forms, viz. plates, shapes, rivets, castings and forgings. Plates are pieces of rectangular cross section which are thin compared to their length and width. The thickness is specified in hundredths of an inch. For calculations of weight a steel plate 1 foot square and an inch thick weighs 40.8 pounds. Thin plates, i.e. those less than about 0.12" thick, are called sheets. Shapes are straight pieces of special

cross section. Some of the common shapes are shown in Fig. 38.

Rivets are used for joining together plates and shapes. The common forms of rivets are shown in Fig. 39.

Castings and forgings are made of a special form to suit a particular requirement such as the stem and sternpost. Castings are used where the part is complicated in form; forgings where it is simple, but neither are used where the part can be built up of plates and shapes because they are both more expensive than built-up structures.

97. Non-structural materials. In addition to the material which is worked into and becomes an integral part of the ship's structure, there is a great deal of material required for specific purposes. Such materials include:

- (a) Non-ferrous metals, particularly non-corrosive alloys, such as the brasses and bronzes for piping and fittings; lead, copper, etc.
- (b) Cast iron for bedplates for winches, etc., checks and bits.
- (c) Steel and iron pipes.
- (d) Wood (on steel ships) for weather decks, gratings, ceiling and sparring.
- (e) Concrete for filling pockets inaccessible for proper preservation.
- (f) Deck coverings, such as linoleum or patented mastic coverings in crew and passenger spaces and tiling in galleys, pantries and toilet spaces.
- (g) Materials for insulating spaces against heat or noise such as cork, felt, etc.
- (h) Paint as a preservative of iron, steel and wood surfaces and for decorative and sanitary purposes.
- (i) Rubber for making watertight joints on doors, hatches, and air ports.
- (j) Glass for windows, air ports, skylights, etc.
- (k) Cordage.

In fact there is at least a little of nearly every material in a large ship. Where a departure from standard commercial practice is involved, or the rules of the classification society require material having greater strength or purity than prescribed by

good commercial practice, such requirements are set forth in the rules.

92. *Kinds of joints.* The hull structure of a ship is formed of a large number of parts. The strength and watertightness of the structure therefore depends not only on the material used but on the strength and tightness of the connections between the individual pieces. Up to about 1911 there was only one method of connecting steel plates and shapes, viz. riveting. Since that time welding has come somewhat into use although the classification societies do not in general permit the use of welded joints in the hull structure. Welding may be used in non-structural members. Considerations which have led to the increased use of welded joints are: (1) a welded joint can be made watertight without caiking, although the quality of the connection is frequently improved by peening; (2) a welded joint does not impair the strength of the material; for riveting a line of holes with resultant reduction of cross sectional area is involved; (3) a saving in weight and cost for welded joints over riveted joints is frequently claimed by welding enthusiasts but for structural work, these claims are not proved. The principal objection to welded joints has been their uncertainty. That is, the strength of similar joints made by the same welder with the same materials and under the same conditions has frequently shown wide variation, and there is no simple way to test welded joints except by destruction. As more is learned of the technology of welding, and its applications are extended in other fields, and welders become more numerous, there will probably be an extension of its use in ship work, but this will most likely be a gradual process and it will probably be a long time before it becomes of major importance in structural work on merchant ships. For the purposes of this work then, the discussion of joints and connections will be confined to riveted joints.

The elementary riveted joint is shown in Fig. 40; all riveted joints are variations of this. The principal reason that the riveted joint is held in such high regard is its certainty. The strength of a joint can be calculated with mathematical exactness and if the riveting is properly done (this can be tested very simply by tap-

ping each rivet with a light hammer), the joint can be depended upon to part at the calculated stress. Many of the problems in shipbuilding are due to the use of riveting, but up to the present



FIG. 40.—ELEMENTARY RIVETED JOINT.

time (1929) these have been considered of less importance than the **definite knowledge** of the **strength** of the connection.

99. Strength of joints. The strength of a riveted connection which is subjected only to shearing stress depends upon: (a) the material of parts joined and rivets, (b) thickness of parts joined, (c) diameter of rivets, (d) distance between rivets in same row, (e) number of rows or rivets, (f) distance from rivet to edge of part joined, (g) distance between rows of rivets. Joints must be designed so that when the member is subjected to any stress the rivets are subject only to shearing stress, for driven rivets have little ability to resist tension. If the members at a joint are pressed together, the rivet has practically no stress. Since the frames have to be secured to the shell plating by rivets, there is a row of holes all around the ship through the shell and deck plating at each frame which reduces somewhat the strength of this plating. The frame rivets have their widest spacing when the frames are non-watertight. Therefore the least inescapable reduction in strength of hull occurs at a non-watertight frame and this is the standard of comparison in theoretical studies of the strength of connections, the strength of the shell plating at a non-watertight frame.

The various problems that arise in shipbuilding in making connections have been studied for many years. As a result, the classification societies have framed rules which cover practically all connections. If a new problem arises a connection must be designed and submitted to the society for approval. The rules for riveting specify the material of rivets and tests to be made, the diameter, the pitch, i.e. distance between rivets in the same row,

the number of rows of rivets, the distance of rivets from edge of plate or angle, the distance between rows of rivets, and type of rivets for all the usual classes of shipbuilding work. This is of great importance to the shipbuilder and naval architect, but not to the operating officer. A riveted joint is spoken of as being single, double or treble riveted according as there are one, two or three rows of rivets. When the rivets in one row are directly behind those in the next row, the joint is chain riveted, when they are not, we have zigzag riveting.

100. Tightness of joints. Joints may be non-watertight, watertight or oiltight. By far the greatest number of joints belong to the first class. All joints in the shell of the ship and certain bulkheads and decks belong to the second class. Ships that carry



FIG. 41.—LAP CALKING.

oil have some boundaries which must be oiltight and consequently require oiltight connections in them. The differences between the ways of obtaining watertightness and oiltightness are in degree not in method. Oil being more searching than water requires more

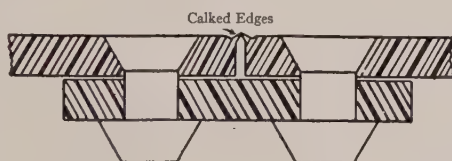


FIG. 42.—BUTT CALKING.

skilled workmanship and more work. In order to draw together the edges of the parts being joined to secure watertightness, the rivets must be closer together than necessary for transmitting the stress from one member to the next. The relative pitch in non-watertight, watertight and oiltight work is about 6:4:3.

In addition to closer spacing of rivets, the edges of the parts joined are calked to obtain tightness at the joint. Figs. 41 and 42

indicate in an exaggerated manner the way in which tightness is obtained by calking. A joint may appear perfectly tight to the unaided eye but unless the metal of the parts joined is brought into intimate contact, such as obtained by calking, the joint is liable to leak. In watertight work it is usually sufficient to calk one side of a joint, in oiltight work both sides are usually calked to eliminate possibility of leakage. Rivets are usually calked in oiltight work and sometimes in watertight work.

In structural work certain cases arise, particularly at the intersection of watertight and non-watertight members, where it is impossible to secure tightness by calking. In such cases a piece of canvas soaked in red and white lead called a stop-water is inserted to secure tightness. Where one boundary is oiltight an oil-stop, which differs from a stop-water only in the substance in which the canvas is soaked, is used. Both materials are termed packing. Tightness may be obtained more cheaply by packing than by calking, but its effectiveness is temporary, while calking is practically permanent. Packing is sometimes used to make good poor work. Excessive use of packing is therefore regarded as evidence of poor workmanship and may be sufficient cause for rejection of the work by the surveyor of the classification society.

Tightness may also be obtained by working a continuous weld at the joint. This is little used in merchant ship work because the rules of the classification societies do not, in general, permit welded joints in structural work where watertightness or oiltightness may be required.

101. Common forms of joints. In *Art. 96* the forms in which shipbuilding steel comes is given as plates, shapes, castings, and forgings and rivets. The last is used to join the other four. The connections may be plate to plate, plate to shape or plate to casting, and the connection may be along long or short dimension of plate and either dimension of other member. The connection may be square or at an angle. There are therefore a great variety of connections in shipbuilding. Some of the more common ones will be described. The connection between two plates is a seam if along the long dimension and a butt if along the short dimension. If one plate is lapped over the other, as in Fig. 41, it forms a seam

or butt lap. If the edges of the joined plates are butted together and they are connected by a third part, as in Fig. 42, the connection is a strapped seam or lap and the piece making the connection is a strap. If there is a strap only on one side of the plates joined, it is a single strap; if on each side, a double strap. Simi-

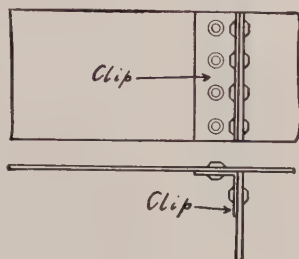


FIG. 43.—CLIP.

larly connection may be made between angles by lapping or strapping. When two plates meet at right angles the connection is made by an angle. Two shapes meeting at right angles may be joined by an angle, called a clip, or a piece of plate (usually triangular) called a bracket or gusset, see Figs. 43 and 44. It happens some-

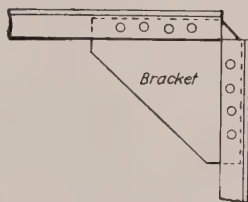


FIG. 44.—BRACKET.

times that a riveted connection cannot be made. This condition occurs where the shell plating joins the stem and sternpost. In such cases tap riveting may be resorted to. A tap rivet is really a bolt with a square shank for screwing into the hole. After it is screwed in, the square shank is cut off and the thread is upset to prevent its backing out.

SECTION B—FRAMING

102. Structural members of hull. The structural members of a hull are the framing, including the stem and sternpost, the shell and inner bottom plating, bulkheads and decks. Each of these is discussed in some detail in this chapter. The framing is the skeleton of transverse "ribs" and longitudinal frames to which the shell plating is riveted. In appearance and function it is not unlike the framework of a building on shore. The shell plating in addition to excluding the water is a very important member of the hull structure contributing materially to the strength of the ship girder. The shell plating forms three sides of the box girder which is the hull; the top or fourth side of the girder is formed by the deck structure. Structurally the deck is a continuation of the shell. The bulkheads serve to stiffen the entire hull structure which otherwise would be too flexible.

The rules of the classification societies give the dimensions of the structural members of the hull. Since most merchant ships are built to class, these rules form the basis for the selection of the structural members of the hull, and there is little the designer can do to change them. The fundamental principle of hull design is that structural members should be just as big as necessary to withstand the stresses to which they are subjected in service, and no bigger. The cost of a hull structure for a given type of ship varies directly as its weight. Therefore the initial cost of a properly designed hull is less than one with redundant strength and therefore excess weight. Redundant strength in addition to contributing to increased initial cost, reduces the paying deadweight on a given displacement and thereby constitutes a tax on the owners during the entire lifetime of the ship. Inadequate strength is likely to lead to failure of the structure which may be responsible for the loss of the ship. From the foregoing, it is apparent that the choice of scantlings of structural members requires the use of careful judgment founded on study and experience.

Plate IV shows typical sections of a class + A.1 ship and are well worth study. Examples of the various details of construction touched upon in subsequent sections will be found in them.

103. Functions of frames. In addition to its function as a part of the ship girder, the framing in the double bottom space forms partitions between the tanks therein. Further, the framing stiffens the shell plating, holding it to its task when this plating is in compression, and it holds the shell to its proper form against the tremendous external water pressure when the ship is afloat. Were it not for the stiffening effect of the longitudinal framing in the bottom of the ship, the bottom plating would collapse when the ship is in hogging condition. Were it not for the support of the transverse frames, the water pressure acting against the sides of the ship would flatten it. Another important function of the framing is to distribute local stresses to other structural members. The transverse frames transmit weights on the decks down to the bottom where these weights are neutralized by the force of buoyancy.

104. Framing systems. Any system of framing consists of members at right angles to each other. Where these members intersect, one may continue through but the other must be interrupted. The member which continues through is called a continuous member, the one interrupted is said to be intercostal. The rigidity of an intercostal frame is much less than that of a continuous frame no matter how much care is taken to secure a good connection.

There are three general systems of framing in current use, the transverse, web frames and Isherwood. The transverse system consists of a large number of closely spaced continuous transverse frames, usually referred to simply as frames and a much smaller number of more widely spaced longitudinal frames, called longitudinals or keelsons. The system of web frames consists of heavy plate web frames spaced about six ordinary frame spaces with continuous light frames between web frames and heavy intercostal longitudinal frames called stringers. The Isherwood system, which is patented, consists of a large number of closely spaced continuous longitudinals and more widely spaced, deeper frames, called transverses. The latter are continuous also except where notched out to permit the longitudinals to pass through.

105. Types of frames. Frames may be formed of one shape such as the angle, Z bar or channel or may be built up of plates and angles. The latter usually consists of a plate standing at right angles to the shell plating with an angle connecting it to the shell and another making the standing flange. The angle connecting to the shell is known as the frame bar, the other angle is the reverse bar and the plate is a floor, see Fig. 45. The floor may be formed of a number of small rectangular plates called

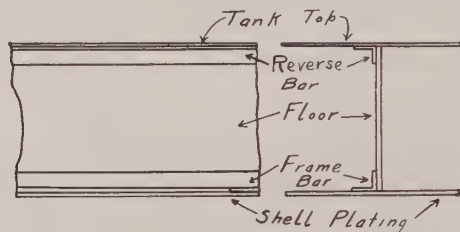


FIG. 45.—BUILT-UP FRAME.

brackets. This is the cheapest kind of construction and therefore used whenever permitted by the rules. Most floors have large holes for access to the various cells or pockets. These holes are lightening holes. Where the frame serves as the boundary of tank or where there are load concentrations, the floor is formed of a solid plate. This is the heaviest and most expensive type of floor.

106. Framing practice on ships of various classes.

(a) **Keel.** The most important frame on any ship is the centerline longitudinal, known as the keel. Plate IV shows the usual type of keel construction for all classes of ships. The angles against the shell and inner bottom plating are both double, i.e. on both sides of the vertical keel which is a solid plate. The flat keel plate and centerline strake of the inner bottom plating are usually considered as part of the keel structure. Sometimes ships have a bar keel below the flat keel plate and riveted to the latter by double angles on the outside. All members of the keel structure are continuous from stem to sternpost.

(b) **Ships having transverse system.** In the bottom of the ship the transverse frames are of the built-up type extending to the turn of the bilge. From there to the lowest structural, com-

plete deck the frames may be either of the one piece or built-up type. The designer here has some discretion in choosing the type of frame which will produce the most satisfactory hull at least cost. Where there is a change in the size of a frame, brackets should be fitted to prevent concentration of stress which always occurs when there is an abrupt change in the size of a structural member. The longitudinals in the bottom (side keelsons or intercostal girders) are of the built-up type. These are intercostal between the transverse frames, but may be given a measure of continuity by continuous upper angles. The longitudinals above the turn of the bilge (stringers) are of the built-up type, similar in construction to those in the bottom but of less depth. In ships having a double bottom, the tank extends to the turn of the bilge where it is terminated by a margin plate, which is a continuous watertight longitudinal. Frames both transverse and longitudinal are more closely spaced in the ends, particularly forward. The spacing of the frames, the dimensions of their component parts and riveting instructions are given in the rules of the classification society.

(c) Web frames. The web frames are built up frames similar to those in the double bottom space of a ship framed on the transverse system. The web frames are continuous to the deck. The floors may be solid or bracket type but when the latter the brackets must be stiffened at the edge to prevent buckling under load. The frames between web frames are usually simple one-piece frames, usually angles, continuous from keel to deck. The side stringers are built up longitudinal frames against the side plating. They are intercostal between web frames and notched out for the intermediate light frames. The lowest must be not less than seven feet above the top of the floors and the spacing not more than eight feet. The spacing of the frames, the dimensions of their component parts, method of fastening, etc., are given in the rules. This type of framing was formerly used a good deal for colliers and other bulk carriers; it has now been largely superseded by the Isherwood system.

(d) Isherwood framed ships. The longitudinals are of the one piece type in the bottom and the built-up type above the turn of the bilge. They are continuous through the transverse frames,

the floors of which are cut out for them. The transverse frames are of the built-up type and derive their continuity from their greater depth. The Isherwood type of construction finds extensive application in tankers and bulk carriers. Ships for miscellaneous cargo and passenger ships usually have the transverse type of framing.

SECTION C—STEM AND STERNPOST

107. Stem. The stem is usually a forged bar. It is one of the end members of the ship girder and the other structural members which extend to the extreme ends of the ship must be well secured to it. The stem is recessed along its after edge to receive the shell plating so that the outside will present a smooth surface to cut through the water. This recess is called a rabbet. The keel structure is securely riveted to the lower end of the stem. The decks support the stem at various intermediate points and at the top. The stem shown in Fig. 46 is the usual type for merchant ships. It is spoken of as a plumb stem to distinguish it from the clipper stem formerly used a great deal on sailing ships.

108. Sternpost. Fig. 47 shows the type of sternpost usually fitted on single screw ships. The sternpost for twin screw ships is simpler because no aperture for the propeller is necessary. The sternpost is usually a steel casting due to its intricate form. It is the aftermost member of the ship girder and must be rigidly secured to the keel, shell plating and decks. The shell plating is rabbeted to the sternpost to give a smooth finish. A sternpost, like Fig. 47, furnishes the outboard bearing for the propeller shaft and has a swelling or boss for that purpose. The sternpost also furnishes the support for the rudder. The vertical part of the sternpost aft of the propeller aperture is called the rudder post. There are three or more projections on the rudder post known as gudgeons through which project pins called pintles which are fastened to the rudder. When the rudder is put over, the pintles turn in the gudgeons.

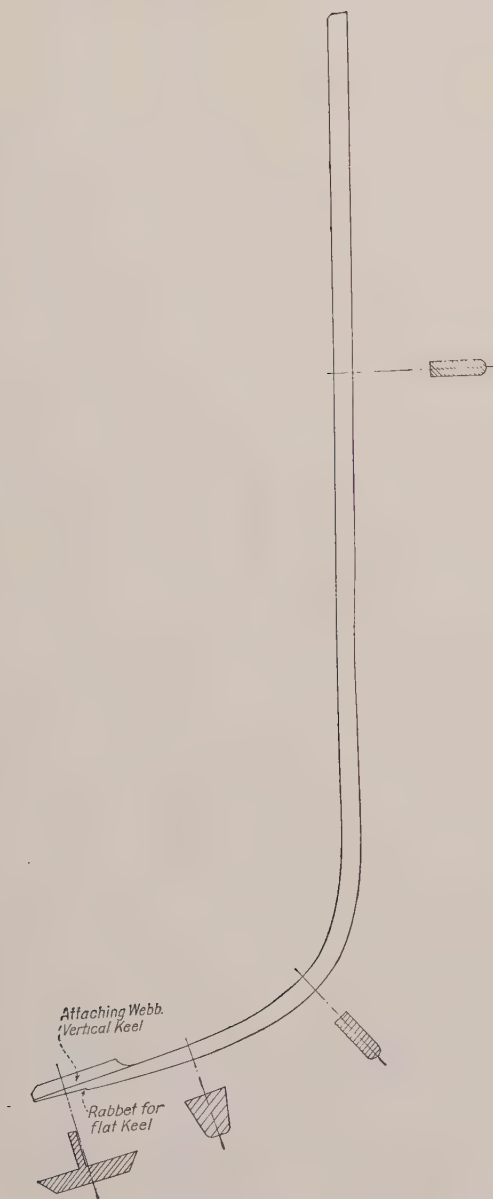


FIG. 46.—STEM.

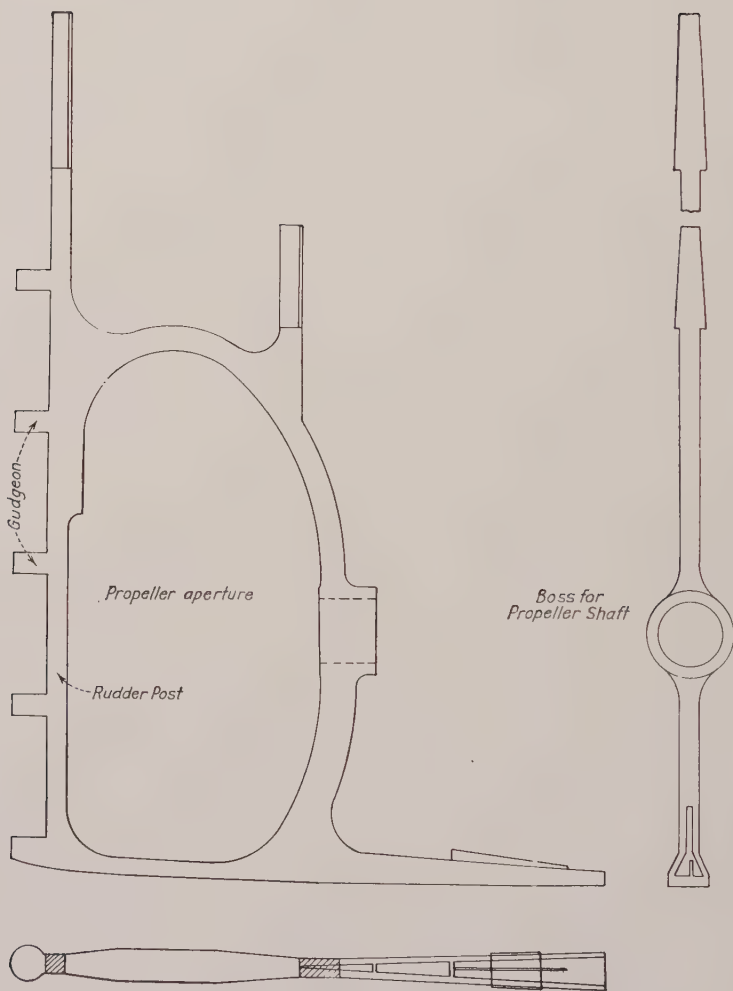


FIG. 47.—STERNPOST.

SECTION D—SHELL AND INNER BOTTOM

109. Functions of shell. The shell plating is the "skin" of the ship. It is important that this skin should be thoroughly watertight, for the ship derives its buoyancy from the ability of the shell to hold its shape against the water pressure and exclude the water. In addition, as explained in *Art. 102*, the shell plating is one of the most important strength members of the hull contributing materially to the strength of the entire structure.

110. Strength and tightness of shell. The shell plating is subject to tension or compression due to tendency to longitudinal bending in the ship girder as explained in Chapter IV. In addition, each shell plate below water is subject to the load of the external water pressure. The thickness of plating is based on these stresses plus a margin for deterioration by corrosion. The thickness of plating is given in the rules of the classification societies. In certain localities on the ship, subject to severe abrasion or galvanic action, such as in way of anchors, the fitting of doubling plates is required.

Shell plating is worked in rows which are called strakes. These strakes are lettered beginning with the strake next to the flat keel. This is the garboard or A strake, the next B and so on. Garboards and sheer strakes are required to be heavier than other strakes, see Plate IV. A riveted joint is not as strong as the unbroken plate. In other words, a butt joint in a strake is a source of weakness. From this, it follows that the butts in adjacent strakes of plating should be separated by several frame spaces, and that there should be as few butts as possible in any frame space. The rules of the American Bureau of Shipping require that there shall be not less than two frame spaces between butts in adjoining strakes within the midship three-fourths length, and that plates shall be at least six frame spaces in length and arranged to provide the best possible shift of butts.

All connections of shell plating both at seams and butts must be watertight. This tightness is obtained by calking the plate edges as explained in *Art. 100*. Calking on the shell is done from the out-

side, this requires some care in the arrangement of joints so that all parts of a seam will be accessible for calking.

111. Plating systems. The joints in adjacent strakes of plating may be made by butting the plate edges together and fitting seam straps, which gives a smooth surface to the ship. This is known as the flush system of plating. It is practically never used for shell plating because it is expensive. When used, a strip of plating of the same thickness as the seam straps must be fitted between frame bar and shell plating between the seam straps. Such a strip is called a liner. In the above case, a parallel liner. In some cases a liner having a triangular cross section is required; this is called a tapered liner. Tapered liners are required between the shell plating and frame bars when clinker plating is used, which is seldom. In clinker plating the strakes overlap each other like shingles on a house.

The system of plating in most general use is the raised and sunken system, also called the in and out system. In this system a raised or outside strake covers the bottom edge of the strake above it and the upper edge of the strake below it. When first introduced a parallel liner was fitted under the frame bar in way of the raised strakes. More recent practice is to offset the frame bar or the plate edges the thickness of the plating to eliminate liners. This offsetting is called joggling and the frame or plate is said to be joggled. See Plate IV.

112. Inner bottom or tank top. Most ships except tankers have an inner bottom about three feet above the bottom shell plating. This inner bottom extends transversely from one bilge to the other and longitudinally between the peak tanks, tanks at the two ends of the ship, which are generally used to give the ship a desired trim by admission or discharge of water ballast. The space between is divided into a number of tanks by watertight frames and longitudinals. The outboard boundary is the margin plate. The original function of the inner bottom was to act as a second bottom to preserve the watertightness of the hull in case of grounding or other damage to the bottom shell plating. In addition to this, it provides a readily available space for adding

ballast in the form of sea water if a ship has to make a trip unladen and therefore with little metacentric height. This space may also be used for the stowage of fresh water or fuel oil. The tank top is also an important strength member of the hull. The combination of tank top, bottom framing and bottom shell plating make a very rigid structure to resist any tendency of the hull to longitudinal bending. The tank top plating is clinker laid with reverse bar or plate joggled to do away with tapered liners. See Plate IV.

SECTION E—BULKHEADS

113. Functions of bulkheads. Bulkheads serve two important purposes. In the first place they stiffen the hull structure compelling the shell to retain its shape against the external water pressure. They also help to distribute topside weights and the forces of buoyancy throughout the hull structure. In dry dock, when the ship is supported on a very narrow strip of her bottom, practically all of the weight of the ship hangs on the bulkheads. In addition to direct stress due to topside weights, the bulkheads are subject to bending stresses because they act like beams supported at the middle (where contact is made with the dry dock blocks) and loaded at both ends by the weight of the side structure. The bulkheads are very important strength members of the hull.

The most obvious purpose of bulkheads is to separate different activities such as machinery space from holds and holds from crew space, etc. Bulkheads which are a structural part of the ship girder are called structural or strength bulkheads, those which act solely as partitions are called partition or non-structural bulkheads.

114. Bulkhead structure. The rules of the American Bureau require that strength bulkheads extending from the bottom to the strength (usually upper) deck will be so spaced that no compartment will exceed 100 feet in length. This is the general requirement. These rules specifically require: (1) a collision bulkhead worked watertight extending from the bottom to the weather deck of flush deck ships and freeboard (usually upper) deck of ships with partial superstructures at distance not less than $5/100$ of the

length from the forward perpendicular; (2) an after peak bulkhead of similar extent and tightness and so worked as to shut off the stern tubes (through which the propeller shafts enter the water) in a separate watertight compartment; (3) watertight structural bulkheads at the ends of the machinery space extending to the upper or superstructure deck depending upon the length of the machinery space and the freeboard; (4) watertight structural bulkheads dividing the cargo spaces extending to the upper deck, the number of such bulkheads depending upon the length and freeboard of the ship. The thickness of plating for these bulkheads is given in the rules. These bulkheads are worked continuous through all decks.

If bulkheads are to be able to stand up against water pressure they must be supported in the same manner that the shell plating is supported by the framing. The supporting frames for bulkheads are called stiffeners. The sizes of stiffeners are given in the rules. Wherever a bulkhead passes through a deck the stiffeners are secured thereto by brackets to give additional support to the bulkheads. Stiffeners are usually bracketed to the tank top or bottom because this is the point of maximum stress if an adjacent compartment is flooded. The method of attachment and size of brackets is specified in detail in the rules.

To secure watertightness at their boundaries, bounding angles are worked all around. These angles are calked to make a watertight joint between bulkheads, shell and decks.

Tankers are required to have a centerline bulkhead extending from the bottom to the top of the expansion trunk and longitudinally the full length of the space in which oil is carried. In the oil carrying space transverse bulkheads must be not more than 30 feet apart and at the ends of the oil carrying space are additional transverse bulkheads forming a cofferdam at least three feet in length. The bounding bars are double, i.e. on both sides of bulkheads.

Non-structural bulkheads may be of light plate, wood, wire mesh or corrugated sheet steel. They are used simply to separate the quarters of one person from another or from galleys, washrooms, etc. They have no stiffeners and extend only one deck height. They are not watertight.

SECTION F—DECKS

115. Function of decks. The decks divide the space inside the hull into a number of layers, thereby facilitating the stowage of cargo, the quartering of crew and passengers, and in general the proper utilization of spaces. The strength deck, which is usually the upper deck, is the top flange of the ship girder. It is a very important strength member and subject to the same tensile stresses due to longitudinal bending of the ship girder as the bottom structure. The deck is supported by the beams and in turn supports these against wracking. Other decks contribute to the structural sufficiency of the ship girder but not to the same extent as the upper deck.

116. Deck structure. The rules of the American Bureau of Shipping require that vessels 400 feet and longer have the strength deck plated. In shorter vessels this requirement is modified to permit omission of some plating at the ends. The deck plating is laid in fore and aft strakes like the shell plating and riveted to deck beams, which in turn are secured to the frames by triangular brackets. In addition to the transverse deck beams, longitudinal frames under the deck, called deck girders, are sometimes worked where necessary to give the deck structure adequate longitudinal stiffness. The outboard strake of deck plating, known as the deck stringer, is heavier than the other strakes as explained in *Art. 77*. The scantlings of all decks, including platforms, which are partial decks, are given in the rules.

Wherever a frame goes through a deck, a hole has to be cut for the frame to pass through. This destroys the watertightness of the deck, which is generally restored in the following manner. The deck bounding angle, known as the stringer angle, is worked at the inner edge of the frame, and the space between the stringer angle and the shell plating is filled with close fitting chocks of wood or plate secured in position and covered with a good body of cement.

Where openings are made in the plated portion of a deck, doubling plates must be fitted to make good the material lost. That is, doubling plates extending outboard from the edge of the hatch

on each side a distance equal to one-half the width of the hatch must be fitted. These doubling plates must be well secured to the plating forward and aft of the hatches, and the corners should be rounded to avoid the concentration of stresses which always occurs at sharp corners. When a deck is severely stressed, failure practically always begins at the corner of an opening. When hatches are so large as to require the cutting of deck beams, the interrupted beams are riveted to a fore and aft frame called a carling which extends between the uncut beams, and transmits the loads from the cut beams to the adjacent uncut ones.

In addition to the support given to the deck beams at their ends by the frames, these are supported at intermediate points by stanchions or pillars. These are fitted in vertical lines to the highest deck. When a stanchion is not fitted to each beam, the intermediate beams are carried by runners under the beams or deck girders. The size of stanchions is given in the rules.

117. Deck coverings. The earliest and most satisfactory deck covering for weather decks over living spaces is wood. Oregon fir, yellow pine and teak are satisfactory woods for this purpose. The specifications for deck planking are very strict, for only the best is satisfactory for this purpose. The portions of weather decks, which under the rules are not required to be completely plated are covered with wood. Fir and pine deck planking should be laid edge grain, i.e. with the grain of the wood vertical, as otherwise it is likely to sliver off. Margin pieces are laid along the waterways and around hatches and foundations for deck machinery. The planking is secured to the steel deck or deck beams by galvanized bolts and nuts. The bolts heads are sunk below the level of the planking and the space above filled by dowels beaded in white lead. The bolts have grommets under the head and above the nut to prevent leakage along it through the deck. The thickness of all planks must be not less than 2-inches if teak and 2½-inches if pine or fir. The edges of individual planks are given a slight bevel and the space between them is filled with oakum and then payed with marine glue. A little space is also left between the ends of planks and similarly caulked and payed. This is to prevent moisture from getting onto the steel deck (when such is fitted) and attacking it

from the top which is hidden and to keep the spaces below free of water when no watertight steel deck is fitted. It also prevents moisture from attacking and rotting the wood at the ends of planks.

Below decks in living spaces linoleum is frequently used in place of wood, although wood is still used a great deal here also. In washrooms, toilets and galleys tiling is frequently used as a deck covering. The American Bureau permits the use of proprietary deck coverings on steel decks not exposed to the weather, moisture or heat, provided (1) the material has no destructive action against steel, (2) is insulated from the steel deck by an approved protective covering, and (3) samples taken by the Surveyor and subjected by him to independent analysis are pronounced satisfactory.

118. Deck nomenclature. On a completed passenger ship the decks are designated by the letters of the alphabet, the highest being the "A" deck, next "B" deck and so on. In the rules of the classification societies and rules for tonnage measurements other terms are used which are likely to be somewhat confusing.

The deck from which the freeboard is computed is the **freeboard deck**. This is frequently the highest complete structural deck and therefore also the **strength deck** and the **upper deck**. If it is also the deck at which the bulkheads terminate, it is the **bulkhead deck**. The upper deck is always the highest complete structural deck, but it is not always the bulkhead deck, the bulkheads may be run a deck height higher to another deck. Also the upper deck while always a strength deck may not be the only strength deck.

In the record book of the classification society, the decks below the upper deck are the **second deck**, **third deck** and so on, and the deck above the upper deck is the superstructure deck or shelter deck. A partial deck at the bow is a **forecastle deck** and at the stern a **poop deck**. Partial decks below the upper deck are called **platforms** or **orlop decks**. The deck below the upper deck is sometimes called the **main deck**. A partial superstructure deck amidships is sometimes called the **bridge deck**. On passenger ships the deck on which the lifeboats are carried is frequently called the **boat deck**. The deck below which the under-deck tonnage is measured is called the **tonnage deck**; in ships having two or more

complete decks it is the second deck from below. Other special names are used sometimes, such as spar deck, awning deck, shade deck, promenade deck, etc.

SECTION G—WATERTIGHT SUBDIVISION

119. Functions of subdivision. A ship is divided into watertight compartments primarily to safeguard her in the event of damage. To float upright a ship must have buoyancy and stability. These in turn depend upon the freeboard and metacentric height. Watertight subdivision limits the loss of buoyancy and freeboard to that due to the flooding of one compartment. If a steel ship had no watertight partitions within the hull one hole through the shell of such size that the pumps could not dispose of the incoming water would cause her loss regardless of its location. Watertight subdivision restricts the loss of buoyancy and reduction of freeboard. Since range of stability depends largely on freeboard, such subdivision also limits the loss of range of stability. Further watertight subdivision limits the area of free surface in a flooded compartment and thereby the loss of metacentric height and initial stability. Watertight subdivision may also prevent the spread of flooding to vital compartments such as machinery space.

120. Standards of subdivision ; Floodable length. The transverse watertight bulkheads on a ship may be so far apart that the flooding of one compartment consumes the reserve buoyancy of the ship and she sinks. Such a ship is no better off as regards watertight subdivision than a ship without watertight bulkheads. Her bulkheads contribute to her structural integrity and separate diverse activities but they do not form an adequate safeguard of the buoyancy and stability of the hull. Such a ship is called a one-compartment ship. Many merchant ships can stand the loss of any one watertight compartment without sinking. Such a ship is called a two-compartment ship. Any damage which destroys the tightness of a main transverse watertight bulkhead and thereby allows two compartments to be flooded causes the loss of the ship. Some ships

can remain afloat with two main compartments open to the sea, these are termed three-compartment ships. Injury to one main transverse bulkhead will not result in the loss of such a ship. All passenger ships operating in the open sea should measure up to the two-compartment standard. This requires a ship at least 500 feet long. A very few of the largest passenger ships conform to the three-compartment standard.

As a result of the sinking of the *Titanic* in 1912, with a loss of 1500 lives, a conference on the saving of life at sea convened in Great Britain early in 1914. This convention recommended a standard of subdivision based on floodable length. The principle enunciated was that the spacing of bulkheads should be such that the floodable length due to one injury would not immerse the bulkhead deck at the ends nor reduce the freeboard of the bulkhead deck to less than three inches. For a given ship a curve of floodable length can be drawn. If the two-compartment standard is adopted the spacing of the bulkheads at any location in the ship's length is equal to or less than the floodable length at that location. In the light of experience of the World War, a closer spacing of bulkheads than 35-feet is not warranted, since this is about the average longitudinal extent of damage by torpedo explosion, and if the bulkheads are closer, it is practically certain that a bulkhead will be destroyed. For protection against torpedo attack the bulkhead spacing should be as great as possible without exceeding the floodable length.

121. Doors, hatches and cargo ports. Doors are watertight, weather-tight or joiner. Watertight doors may be of the sliding type, either vertical or horizontal, usually power operated, or hinged. Sliding watertight doors secure tightness by riding up on a wedge which presses a machined surface around the edges of the door against a similar surface on the door frame. These are usually preferred where coal or other material is likely to partially block the doorway. A hinged watertight door is shown in Figure 48. These are lighter and cheaper and are used except where the rules require sliding doors. **Experience has shown that as safeguards of the watertight integrity of a ship watertight doors are a delusion.** They are usually kept open and frequently

there is no one handy to close them in an emergency. The gaskets and machined surfaces are frequently allowed to deteriorate and do not make a watertight joint. They are frequently subjected to mechanical injury which prevents their proper closing. **They are, nevertheless, greatly to be preferred to arches with no means of closing or non-watertight doors, for even if not watertight they greatly retard the flow of water from one space to another.**

The essential difference between watertight and weather-tight doors is that the former is designed to remain tight under pressure while the latter is supposed simply to exclude rain and spray but may leak under pressure. Weather-tight doors have fewer dogs than watertight doors and frequently have no rubber gaskets.

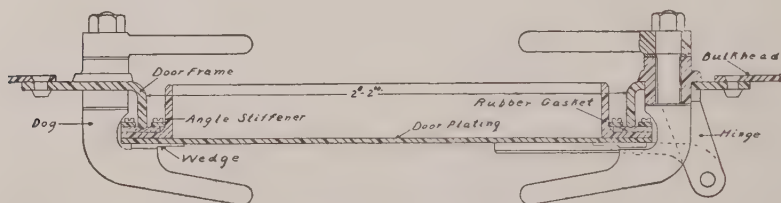


FIG. 48.—HINGED WATERTIGHT DOOR.

Joiner doors are wood or metal doors such as used ashore. They are used only in passenger and crew spaces in partition bulkheads.

Where access through a watertight deck is required, a watertight hatch or bolted plate may be fitted. The former is like a hinged watertight door except that its plane is horizontal instead of vertical. The latter consists simply of a plate bolted instead of riveted to the deck. A reinforcing ring is fitted around the opening in the deck and the plate is set in a gasket of canvas soaked in red lead. Access to the tanks in the double bottom is usually obtained through such bolted plate manholes.

The main cargo hatchways of a ship usually go right through all decks. These hatchways are required to have coamings extending from the bottom of the deck beams to a height of at least 24 inches above the freeboard deck or superstructure decks forward of the midship half length and 18 inches above other superstructure weather decks. These coamings must be adequately stiffened and

braced and provided with fixtures for securing the tarpaulins which are hauled over the wooden hatch covers to protect the cargo. Hatch beams must be provided so that the unsupported length of hatch cover does not exceed $4\frac{1}{2}$ feet for hatches required to have 24 inch coamings and $5\frac{1}{2}$ feet for those permitted to have 18 inch coamings. These wooden hatch covers are required to be not less than $2\frac{1}{2}$ inches thick and to have at least $2\frac{1}{2}$ " wide supports at the ends. They must be strengthened by cleats spaced not more than 2 feet center to center from end cleats which are not more than 6 inches from hatchway corners. Wedging or other battening arrangements satisfactory to the classification society must be provided. Locking bars across cover boards should be provided to seal hatches for customs and prevent pilferage of cargo.

Engine and boiler hatchways are required to be protected by superstructures enclosed by plate trunks extending at least 6 feet above the superstructure deck. The scantlings of these trunks are given in the rules.

Permanent companionways in exposed positions on weather decks are required to be covered by steel hoods riveted to deck plating. Deck openings for masts must have coamings equal in height to one-third the diameter of the mast or 9 inches, whichever is less.

Passenger ships frequently have large ports in the side for admission of passengers, baggage and coal. Those for passengers and package cargo are built like hinged watertight doors, but being larger must be of thicker plate and in addition are usually stiffened by webs normal to the plane of the port. They make up watertight against a rubber gasket. Such openings are not permitted in the sheer strake because they would destroy its continuity and consequently its efficacy as a strength member. Ports for admission of coal have guard plates on the inside to protect the hinges. They make up watertight against a canvas gasket soaked in tallow and white lead. Rubber gaskets are unsatisfactory here due to liability to mechanical injury.

122. Tests of watertight boundaries. The requirements of the American Bureau of Shipping for the testing of watertight

boundaries are given; the requirements of other classification societies are similar.

(a) **Bulkheads.** Hose testing of watertight bulkheads, recesses and decks is to be carried out after completion of all work affecting watertightness; the test is to be carried out under simultaneous inspection of both sides of the plating; the pressure of water in the hose should be not less than 30 lbs. per square inch.

(b) **Decks.** Watertight decks are to be subjected to hose testing after all fittings are fastened in position; the pressure of water in the hose is not to be less than 30 lbs. per square inch. Gutter waterways are to be tested by flooding or hose testing before any cement is laid. In passenger spaces the requirement as to hose testing may be modified.

(c) **Deep tanks.** Deep tanks are to be tested with a head of water equal to the height of the load draft, two-thirds the depth of the hull or one foot above the highest point to which the water may rise under service conditions, whichever is greatest.

(d) **Double bottoms.** Before the vessel is launched and before the cement is laid at the tank ends or outside the margin angle, double bottoms are to be tested with a head of water up to the freeboard deck, the bulkhead deck or the overflow from the air pipes, whichever is the highest. Where engines are bolted direct to tank tops, the tanks in way of same are to be finally tested after the engines are fixed in place.

(e) **Spaces for stowage of oil in bulk.** All oil spaces and cofferdams are to be tested before the ship is launched or when in dry dock with a head of water at least one foot above the highest point to which oil has access in pipes, hatchways or elsewhere, or to a head of not less than six feet above the highest point of the expansion trunk, whichever is highest.

(f) **Tunnels.** Testing of shaft and other watertight tunnels is to be carried out upon the completion of all work which affects their watertightness. The tunnel may be subjected to a water pressure test or may be hose tested. If hose tested the pressure in the hose is not to be less than 30 lbs. per square inch and the test is to be carried out under simultaneous inspection on both sides of the plating.

CHAPTER VIII

HULL FITTINGS

SECTION A—STEERING APPARATUS

123. Rudder. The usual forms of rudders and the considerations governing their area were discussed in *Art. 69*. The discussion in this article is confined to their structural arrangements. The parts of a rudder are stocks (upper and lower), frame (composed of lower stock and arms), arms, blade, pintles and crosshead, tiller or quadrant. All of these parts may be iron or steel forgings or steel castings of approved design. The plans of the rudder must be submitted to the classification society for approval. The upper stock is usually bolted to the lower stock for convenience in unshipping. The arms are horizontal members which are required to be keyed or shrunk on to the lower stock. These arms are usually so arranged as to be alternately on opposite sides of the plating forming the blade which plating is riveted to them. The pintles are required to be fitted as taper bolts. Stops must be fitted on deck to limit the angle to which the rudder can go. Bearing rings are fitted under the rudder arms or carriers to distribute the weight of the rudder. The pintles are the pivots on which the rudder turns and must be strong enough to take the pressure generated when turning at full speed with full rudder. The diameter of rudder stocks and pintles, the size and spacing of arms, thickness of plating forming the rudder blade, and the details of fastening the different parts together are all given in detail in the rules. The rudder stock is keyed to the tiller or quadrant which is actuated by the steering engine through some form of steering gear.

The rudder described above is the usual type for merchant ships. Recently several patented types of stream line rudders have been introduced which are reported to reduce the resistance and thereby reduce the fuel consumption per day for the same speed or shorten

the time required to make a given run on the same fuel consumption.

124. Steering gear; Steering engine; Control gear. The steering gear is the mechanism which transmits the motion of the steering engine to the rudder. There are a large variety of steering gears and steering engines. The most usual type of steering engine is a reciprocating steam engine having a differential valve which in turn is opened by operation of the steering wheel on the navigating bridge. This engine has a drum with two wire ropes, one leading to the starboard side of the quadrant or tiller and the other to the port side. These wire ropes connect to a piece of chain near the tiller or quadrant. They have springs to take up the stretch. When the steering wheel on the bridge is turned clockwise the differential valve on the steering engine is opened and admits steam to the engine to cause the drum to wind up the line leading to the one side of the tiller quadrant and pay out the line leading to the other side which action moves the rudder to starboard. This is known as porting the helm, a term from the old sailing days when the helm or tiller was attached directly to the rudder. When the helm was put apart, the rudder and ship's head went to starboard. When the steering wheel is turned counter-clockwise the differential valve on the steering engine admits steam to cause it to revolve the drum in the opposite direction and the ship's head goes to port. Recently there have been produced automatic steerers operated by gyro compass.

Ships having a steering engine are required to have an entirely independent means of steering by hand or other power, efficient brakes or other satisfactory means for steadying the rudder in the event of a breakdown necessitating a change of gear and satisfactory arrangements for stopping the gear before the rudder stops take effect. The radius of the tiller or quadrant is required to be at least seven times the diameter of the rudder stock; the depth of boss and breadth of the arm should be equal to the diameter of the stock and the thickness of the arm should not be less than half its breadth. In quadrants the breadth and thickness of the arms may each be 85% of those of a single arm if two, 77% if three, and 70% if four in number. The diameter of the steering

chains is $14\frac{1}{2}\%$ and the rods $17\frac{1}{2}\%$ of the diameter of the rudder stock. Sheaves for providing fair leads for steering chains are required to be twice the diameter of the rudder stock and so located as to avoid sharp angles. Steering chains must be tested in accordance with the rules of the society.

SECTION B—GROUND TACKLE AND HANDLING GEAR

125. Anchors and anchor chain. The numbers, weights and sizes of anchors, chains and hawsers for a ship to get the highest classification under the American Bureau of Shipping + A.I.® are based on the tonnage under the upper deck.

$$\text{Tonnage under upper deck} = \frac{L \times B \times D \times C}{100}$$

where L = length, B = breadth, D = depth of ship, and C = block coefficient at 0.8 of molded depth with 0.75 as a maximum.

This tonnage is augmented for superstructures by an amount given by the following:—

$$\text{Addition for superstructure} = \frac{l \times b \times d \times 0.75}{150}$$

where l = length, b = breadth at upper deck amidships, and d = mean height of 'tween decks.

The weights of anchors given in the rules are exclusive of the weight of the stock which must weigh one fourth as much as the anchor. Stockless anchors may be used but in that case 25% must be added to the tabular weight of the anchor given in the rules. The weight of the head of the anchor must be at least 60% of its total weight.

The number of anchors, the weight of each, the length of chain and its size, and the sizes and lengths of hawsers and towlines for any particular ship are given in the rules.

126. Hawse and chain pipes; Chain locker. The pipe through which the anchor chain passes between the anchor windlass and the water is known as the hawse pipe. The compartment in which the anchor chain is stowed is the chain locker. The pipe

through which the chain passes between the chain locker and the windlass is a chain pipe. Chain pipes are similar in manufacture to the hawse pipes but need not be as strong particularly when, as usually, the chain has a straight drop from the windlass to the chain locker. The requirements of the American Bureau of Shipping for hawse pipes are given. Hawse pipes are to be of ample size and strength; they are to have full round flanges and the easiest possible lead in order to minimize the nip on the cables (anchor chains); they are to be secured to thick or double plating by rivets spaced seven diameters and after installation are to be hose tested for watertightness using a water pressure of 30 lbs. per square inch in the hose. Hawse pipes for stockless anchors are to provide ample clearances; the anchors must be shipped and unshipped in the presence of the surveyor to demonstrate the certainty that they will not jam in the hawse pipe.

The ends of the anchor chains are usually made fast in the top of the chain locker in such a way that the securing will part before the tension on the chain will be great enough to part it or wreck the structure. The chain locker is similar in construction to a deep tank. Some masters keep the cable covered with fresh water to prevent rusting.

127. Anchor engine and windlass. The anchor windlass on merchant ships is usually installed on the forecastle deck. It is usually operated by a steam reciprocating engine through worm gearing. The drums over which the chain cable passes (known as wildcats) have projections (whelps) to fit the links as they come over. By means of a clutch the wildcats may be made to revolve with the shaft driven by the anchor engine or allowed to turn freely. Brakes are fitted to control the speed of the wildcats when disconnected by means of the clutch. When veering, the clutch is disconnected and the wildcat controlled by the brake; when heaving-in, the clutch is connected up. When it is desired to pay out only a link or two the engine can be walked back. Care must be taken to ensure a fair lead for the chain from the chain pipes to the wildcat and from that to the hawse pipes. The windlass must be securely bolted down and the deck beams below it are required to be of extra strength and supported by stanchions or bulkheads.

SECTION C—MISCELLANEOUS DECK EQUIPMENT

128. Masts and booms. No discussion of masts or spars for sailing vessels is given herein. The requirements for such are fully covered in the rules of the classification society. On other ships masts are primarily for the purpose of handling cargo. Such masts are usually made of steel plates rolled into cylindrical form. The derrick booms may similarly be of steel but they are more generally wooden spars. The American Bureau of Shipping accepts no responsibility for the sufficiency or efficiency of cargo gear but makes certain recommendations which ships classing thereunder must conform to and requires the submission of a mast plan showing the positions of derricks on masts, weights which they are to handle, the construction of derrick tables and the stiffening in way of derricks. The scantlings of the mast from below the wedging at the deck which supports the mast laterally to well above the derrick are obtained by the following formula:—

$$W \times O = 0.6 d^2 t$$

where W = weight hoisted in tons, O = maximum outreach in feet, d = diameter of mast in inches, and t = thickness of plating in inches.

Masts must be properly stayed to meet load conditions.

129. Deck winches. In locations convenient to the hatchways and derricks, deck winches, for whipping the cargo in and out of the holds, are installed. These are usually operated by reciprocating steam engines, although on recent ships having Diesel engines, motor driven winches are coming into use. The winch has one or more drums on which one part of the hoisting line is wound or unwound.

130. Anchor cranes; Boat davits; Hatch davits. Ships having old style anchors which are carried on bill boards must have cranes for handling the anchors to the bill boards. Fig. 49 is a diagrammatic representation of an anchor crane in accordance with the rules of the American Bureau of Shipping. These rules give formulas for computing the diameters of the main post, jib

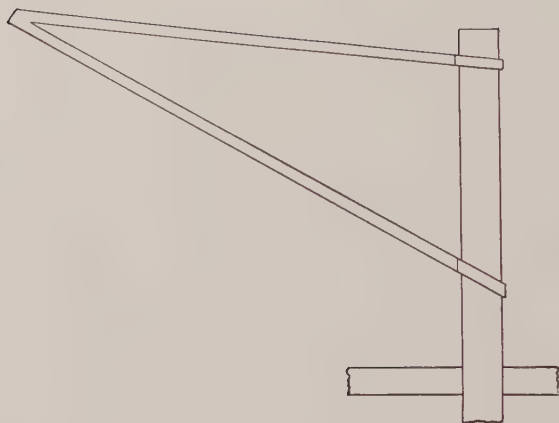


FIG. 49.—ANCHOR CRANE, DIAGRAMMATIC SKETCH.

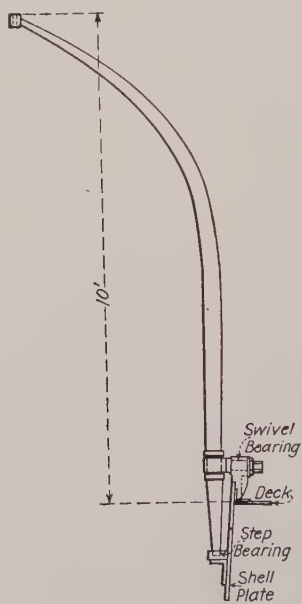


FIG. 50.—BOAT DAVIT.

and tie rod based on the total weight of anchor and stock and outreach of crane.

Fig. 50 shows an old style boat davit. Davits for handling weights at hatches or elsewhere, for handling the side ladders, etc., are similar in appearance. The rules give a formula for computing the diameter of boat davits. In general it may be said that the diameter of a davit depends upon the weight carried, height and outreach. Due to the difficulties of handling davits like Fig. 50 in an emergency requiring rapid embarkation, as in the case of the sinking of a passenger ship, such ships are usually fitted with some form of patent davit, of which there are numerous kinds which are acceptable under all rules.

131. Boat stowage arrangements. On freighters the boats are usually stowed on the midship superstructure, if there is any; on passenger ships they are stowed on the highest deck, and if that will not accommodate all of them, some are stowed on the next deck below. The boat falls are kept connected at all times ready for immediate lowering and the boats rest either directly on the deck or on a fore and aft piece which supports the keel. The boat is held upright by chocks fitted to conform to its shape and the outboard half is frequently hinged to facilitate getting out the boat. Sometimes two boats are required to be lowered by one davit; in this case the chocks for the outboard boat are readily removable.

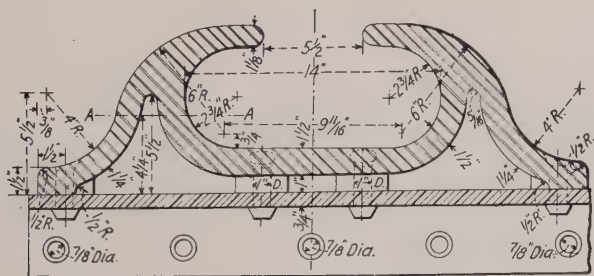


FIG. 51.—ЧОК.

132. Bitts and chocks. Bitts for securing mooring lines and chocks for giving them a fair lead over the side should be provided

all along the ship's length, particularly at each quarter. In very high sided ships the chocks are simply openings in the side with a round beading to prevent chafing the lines. Those set on a weather deck are usually two horns with an opening between, see

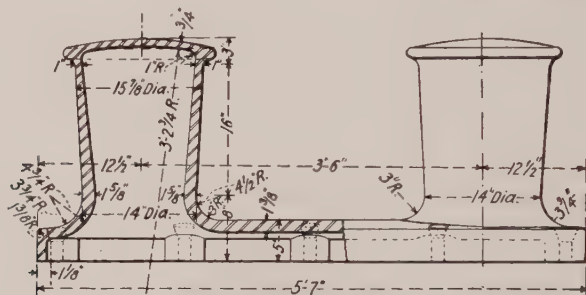


FIG. 52.—BITTS.

Fig. 51. Fig. 52 shows a pair of bitts of ordinary form. Both of these are usually made of cast iron and it is essential that they have no sharp edges to chafe the lines.

133. Donkey boiler. Most ships have a donkey boiler which is located outside of the machinery spaces. It is used to furnish steam for heating, cooking, etc., when there is no steam on the main boilers. Diesel driven ships require the use of a donkey boiler at practically all times.

SECTION D—MISCELLANEOUS EQUIPMENT BELOW DECKS

134. Refrigerating plant. If the refrigerating machinery and insulation of cold storage spaces is in accordance with the requirements of the American Bureau of Shipping and has been installed under the inspection of a surveyor of the Bureau it is given the classification symbol + R.M.C. If complying in all respects with the rules but was not inspected during installation the symbol + is omitted. The continuance of classification is subject to survey of the plant at the end of each voyage exceeding three months, and in the case of ships making shorter voyages, at intervals not

exceeding three months. Any reliable type of refrigerating machinery may be used but it must be capable of maintaining the required temperature in the tropics on 18 hours' operation per day and carry spares in accordance with lists furnished in the rules. Further, if the refrigerated space exceeds 70,000 cubic feet the machinery must be in duplicate. The machinery space must be separated from the insulated space by a watertight bulkhead or deck. The insulating material is usually cork of thicknesses up to six inches. It must cover completely the interior surfaces of the cold storage compartment including beams, stiffeners, brackets and any other projections. Provision must be made for examination of bilges in refrigerated spaces. Battens $2'' \times 2''$ on the bottom and $2'' \times 1\frac{1}{2}''$ on the sides, spaced 12'', must be fitted to protect the insulation from the cargo.

135. Ceiling and sparring. In ships with single bottoms, close ceiling $2''$ to $2\frac{1}{2}''$ thick is required to be laid on top of the floors covering the flat part of the bottom and extending to the upper part of the bilge, this ceiling to be in sections for easy removal for inspection of the bottom. In double bottom ships ceiling is required only under the hatchways and at the sides between the margin plate and the upper part of the bilge. Such ceiling must be laid on $1\frac{1}{2}''$ battens or bedded in a mixture of tar and cement.

Sparring is required to be fitted above the ceiling in all cargo spaces in which it is intended to carry general cargo. Such sparring must be $2''$ thick and must provide the same degree of protection as given by nine inch batten and space alternately. Such sparring is usually fitted in cleats attached to the reverse face of the frame for ease of removal. It is generally installed fore and aft, although vertical battens are permitted. No sparring is required in coal bunkers. Spruce, pine and fir are used for ceiling and sparring.

No ceiling or sparring is required in bulk carriers but the inner bottom plating is required to be increased in thickness and worked flush.

SECTION E—OUTBOARD FITTINGS

136. Shaft struts and spectacle frames. Ships having two or more screws have two or more propeller shafts off center. These shafts must be supported after they leave the fair line of the hull. Merchant ship practice has been to build out a bossing called spectacle frames to carry these shafts. Naval practice has been to fit cast steel struts. Spectacle frames show less resistance. The plating of spectacle bossing must be 10% thicker than ordinary shell plating in the same vicinity.

137. Bilge keels. The ability of bilge keels to reduce rolling has been thoroughly proved. Practically all ships are fitted with such at the turn of the bilge extending nearly the full length of the hull. Bilge keels usually consist of a plate about 12" deep standing at right angles to the shell plating and secured to it by double angles.

138. Sea valves, cocks and chests. Sea valves must be so placed as to be easily worked from the engine room platforms. When they make connection with the sea through the double bottom or otherwise so as to require a long neck if fastened directly to the shell, they are attached to steel sea chests which are built on the inside of the shell plating. Frequently a strainer is provided in the opening in the shell to prevent the entry of foreign matter. Sea cocks and valves fitted direct to the shell must be secured with tap bolts or bolts with countersunk heads tapped through the plating. This is to eliminate the possibility of some object striking the head of a bolt and starting a leak through the shell.

CHAPTER IX

HULL SYSTEMS

SECTION A—DRAINAGE SYSTEMS

139. Drainage below decks. The purpose of the drainage system for spaces below decks is to rid such spaces of small amounts of water due to minor leakage of shell plating or decks. It does not have sufficient capacity to cope with the inflow of water through a large opening resulting from grounding, collision or underwater explosion. The system consists of pumps, piping, valves and sea connections. Formerly all ships were required to have for draining cargo holds and peak tanks hand pumps which were never used in operation. Such are no longer required provided the ship has power operated pumps which can be controlled from the bulkhead deck or highest convenient level which is always accessible. The pumps should be capable of taking a suction from any watertight compartment when the vessel is on an even keel and erect, or has a list of 5° . In addition the donkey pump must have an independent suction to the engine room bilge and the main circulating pumps should have direct suction connections to the lowest drainage level in the machinery space. This last is capable of dealing with large quantities of water. Drainage connections must be entirely independent of connections for filling or emptying spaces where water is carried either for ballast or other purposes. The rules give formulas based on length, beam and depth of ship and length of compartment from which the diameters of drainage mains and branches may be computed. Drainage mains must not be less than $2\frac{1}{2}$ " and branches not less than 2" nor more than 4" diameter. The diameter of ballast suctions depends upon the capacity of the tank; sizes are given in the rules. The drainage from flat surfaces such as tank tops, machinery spaces and tunnels are to be from bilge wells similar to Fig. 53. Drainage piping must

be protected from damage, adequately supported and provision made for expansion.

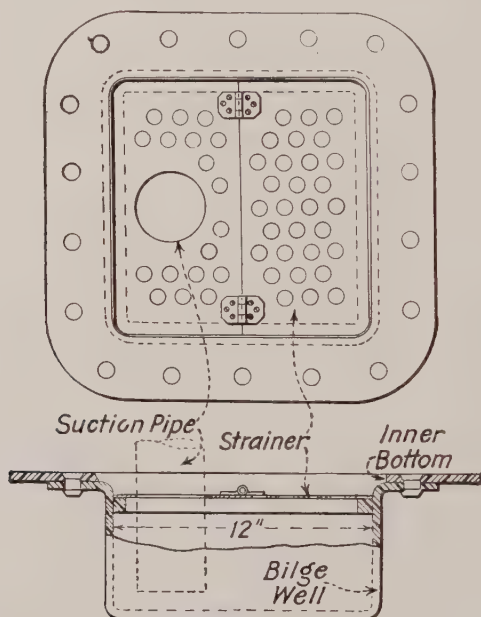


FIG. 53.—BILGE WELL.

140. Scuppers and deck drains. Watertight decks usually have a gutter or waterway around them from which water on the deck is removed by scuppers, which are castings which have openings (usually covered by strainers) in the waterway and discharge to pipes leading overboard through a storm valve. The last is a flapper hinged at its upper edge so that water can flow out but the seas cannot enter into the ship through it. Scuppers and sanitary discharges from fully enclosed superstructures or decks below the freeboard deck must be fitted with an approved, accessible means of preventing water from passing inboard in addition to the storm valve.

Wells which are enclosed by bulwarks must have freeing ports to get rid of the large volumes of water which may fill them to a depth as great as five feet. Such freeing ports must have an area

equal to 5% that of the bulwarks. These freeing ports may be simple open railings or holes cut in the bulwark plating.

141. Air escapes and sounding tubes. Air pipes not less than 2" diameter must be provided at each corner of each ballast tank; the total area of the pipes must always be greater than that of the supply pipes (twice as great in the case of deep tanks). Perforations in structural members inside the tank or other means are to be provided to permit the free flow of air from the tanks to the air pipes during filling. When the tank top is not flat, the air pipe must be fitted at the highest point.

Sounding pipes must be provided for each compartment and ballast tank with a thick doubling plate securely fixed under each pipe for the rod to strike on. Such pipes are to be without bends and to extend directly into the compartment to be sounded. The upper ending is to be on the bulkhead deck or in a position below it which is always accessible, and if they terminate below the bulkhead deck they must have non-detachable screw caps.

Air, sounding and suction pipes are to be protected against damage from cargo, coal, etc.

SECTION B—VENTILATION AND HEATING SYSTEMS

142. Ventilation of spaces. There are two general methods of ventilating spaces: natural and forced. The latter may be either supply or exhaust. Spaces in superstructure usually have only natural ventilation; passenger spaces below decks usually have forced ventilation. Forced ventilation except for galleys, toilets and hospital spaces is usually supply. The draft for the operation of the boilers is sufficient for the ventilation of fire rooms whether this be natural or forced draft. Machinery spaces frequently have forced, supply ventilation and when they do not, provision is usually made for rigging windsails in the tropics. All holds, 'tween decks and bunkers are required to have two ventilators placed as nearly as possible at the ends of each compartment and a ventilator must be led into peak tanks, tunnels and other watertight compartments where gas may accumulate or forced ventilation

must be provided for these spaces. The dimensions and scantlings of ventilator coamings and cowls are given in the rules. Ventilator coamings must be provided with wood plugs and canvas covers or watertight metal covers which can be rapidly secured in place to prevent seas from entering the spaces through the ventilators. Special arrangements for keeping all compartments clear of explosive gases are required on tankers.

143. Heating of spaces. Quarters for operating personnel and passengers must be provided with means of heating. Such heating may be by means of direct radiation from steam or electric radiators or in combination with forced supply ventilation by passing the fresh air over heated coils. Since most living spaces on freighters have natural ventilation, the heating of such is usually by direct radiation. Some passenger ships use the indirect heating system.

SECTION C—FIRE PROTECTION SYSTEM

144. Fire main and fire plugs. The best way to fight a fire in a cargo hold or a bunker is to close it airtight and thereby smother the fire. There are provided on the upper and superstructure decks and passenger spaces, fire plugs to which hose can be attached for extinguishing fires in such localities. These fire plugs are connected to a main which is supplied with water by a pump in the machinery space. The fire plugs are also used to supply water for washing down the decks in the morning watch.

Ships carrying oil either cargo or bunker usually have some special apparatus for covering the surface of oil in tanks with a blanket of air-excluding foam or of filling the space above the oil with steam so that any oil fire may be quickly extinguished, on account of the difficulty of dealing with an oil fire which gets a good start.

145. Sprinkling systems. Passenger spaces frequently have automatic sprinklers in which the melting of an alloy of low melting point opens a valve and sprinkles any fire which may be in

the immediate vicinity and rings an alarm at some location where someone is always on watch. Bunkers and cargo holds frequently have thermostats to give warning when the temperature therein rises to a dangerous point.

SECTION D—SANITARY SYSTEMS

146. Wash water system. The staterooms of officers and passengers and washrooms of crew, galleys, hospital, etc., must be supplied with fresh water, hot and cold. The usual system is to have a small fresh water pump operating continuously keeping a pressure on the system, circulating cold fresh water from the fresh water tanks to the various taps. Hot water is obtained by passing cold water through a heater operated by steam or electricity.

147. Flushing system. Salt water must be supplied for flushing water closets, for washrooms, galleys, etc. The usual system is to have a small pump operating continuously keeping a pressure on the system at all times.

148. Plumbing system. This system discharges refuse and water from water closets, washrooms, galleys, etc. It consists of gravity drains overboard through scuppers. Special provision must be made for clearing these scuppers and cleansing by steam.

CHAPTER X

FUEL HANDLING AND STOWAGE

SECTION A—COAL

149. Coal handling gear. Coal is usually taken aboard through large hatchways in the deck on freighters and through cargo ports on the ship's side on passenger ships. Merchant ships usually have little coal handling gear, the bunkering of a ship usually being performed by the firm supplying the coal. Various types of conveyor machinery for the rapid bunkering of ships have been devised and are in use today. The more usual type consists of a grab bucket which hoists coal to a hopper at such a height that the coal may flow by gravity through an adjustable chute into the bunker. When a bunker is nearly full some trimming may be required before closing the hatch.

150. Bunkers. Bunkers for coal are not unlike the cargo holds except that they are usually shorter and have no sparring and ceiling. The bunkers are usually just forward of the fire room and the watertight door through the bulkhead between the fire room and bunker is of the sliding type. In small vessels the bunkers are sometimes outboard of the fire room and separated from it by non-watertight partitions. The hatchways of bunkers are similar to those of cargo holds. Owing to the moisture present in the coal when received the structural steel of bunkers is very subject to corrosion and must be carefully covered by a protective coating.

SECTION B—OIL

151. Oil piping. Ships burning oil in their boilers have a filling connection on each side on the upper deck for taking oil from

an oil barge or shore oil line. This leads to a manifold in the machinery space by means of which the oil is directed to the various tanks. Suctions from the oil tanks to the pumps which deliver it to the boilers are also provided. Owing to the penetrating quality of fuel oil and its ability to dissolve rubber, which is commonly used in gasket material, the best workmanship and gasket material is essential in installing oil filling and suction piping. In tankers a piping connection is sometimes made so that in event of emergency, oil for the boilers may be drawn from a cargo tank.

152. Oil tanks. Bunker oil is stored in tanks which on tankers are entirely independent of the cargo tanks. The only connection is one for use only in emergency when the oil in the ship's oil tanks has been consumed, lost or contaminated so that it cannot be burned. The spaces most commonly used as oil tanks are the double bottom compartments under the engine room. Sometimes oil is carried in deep tanks forward of the fire room. No oil may be carried in a space adjacent to a fire room or cargo hold. Where this condition would occur, a cofferdam at least three feet wide, oiltight and well ventilated must be provided between the oil tank and the fire room or cargo hold. Oil is never carried in the double bottom compartments under the fire room. Owing to the searching quality of fuel oil the best workmanship is necessary to secure absolute tightness of the boundaries of fuel oil tanks.

CHAPTER XI

PRESERVATION

SECTION A—PROTECTIVE COATINGS

153. Deterioration of metal surfaces. Metal surfaces are subject to deterioration due to corrosion and erosion. The former may be simply rusting or electrolysis, both of which are chemical actions; the latter is due to mechanical wear and of relatively little importance in ships except those carrying coal and ore in bulk. Rusting of steel takes in air due to the combination of the atmospheric oxygen with the steel to form iron oxide. This reaction is accelerated by the presence of moisture and heat. The bottoms of the bulkheads, tank top, and shell in machinery space are therefore subject to rapid deterioration from this source. Rusting is a progressive reaction and if a piece of steel is left under conditions conducive to rusting, the reaction continues until all the steel is changed to iron oxide. In fact the formation of rust which is porous, and therefore holds water like a sponge, accelerates the speed of the chemical transformation. The iron oxide formed by rusting occupies much more space than the steel it replaces (ratio about 8:1). The formation of rust in a joint between two members may put such stress on the rivets as to pop off their heads. The formation of rust on the structural members of steel ships must therefore be prevented.

Electrolysis is the reaction which occurs when two dissimilar metals are immersed in an acid solution. An electric current is set up and the metal which forms the positive pole of the cell is gradually eaten up. Certain brass and bronze fittings are used on board ship; propellers are frequently bronze. Sea water is slightly acid. Steel is electropositive to most metals. The electrolysis of the steel hull of a ship must therefore be guarded against.

In addition to these destructive reactions, the underwater body

of a ship afloat in salt water is soon covered by marine growth, both vegetable and animal. This is known as fouling. The adherence of this growth increases the resistance of a ship materially as explained in Chapter III, and thereby slows her down and increases her fuel consumption (operating cost). Therefore this must also be prevented.

154. Classes of protective coatings. Protective coatings may be classified as (a) paints, (b) cement, (c) bituminous compositions. A fourth form of protector for the hull are zinc plates attached to the rudder post and other locations where steel and some other metal are close together in the water. Zinc is electro-positive to steel and therefore if any galvanic action is set up, the zinc protectors are consumed instead of the steel hull. The zinc protectors are replaced as necessary when the ship is dry docked.

(a) Paints. A paint is a mixture of a pigment (frequently a metallic substance such as lead oxide, zinc oxide, zinc carbonate, etc., ground very fine), and a vehicle (linseed oil, petroleum spirits, etc.). Driers and thinners may also be present in a paint. Paint protects a surface by excluding the air or water. The oil upon drying forms a tough, elastic membrane which is somewhat porous and the finely ground pigment fills the pores, thereby forming an absolutely airtight coat on the surface which will expand and contract with the steel. Bottom paints frequently contain powdered zinc which also tends to prevent any galvanic action. Bottom paints usually contain certain substances which are poisonous to prevent the adherence of any marine growth.

(b) Cement. Cement is a mixture of Portland cement and sand. The rules of the American Bureau require that the bottom up to the turn of the bilge shall be protected by cement (two parts sand to one part Portland cement), or other approved material covering the plates, frames and rivet heads, of a thickness not less than $\frac{3}{4}$ ". The inside of tanks may and usually is protected by cement also. Two coats are required; the first coat is very thin, called cement wash, and is applied with a brush.

(c) Bituminous compositions. These are proprietary compounds composed of a bituminous pitch and Portland cement. They are efficient protectors of steel surfaces but not pleasing in appear-

ance. Their use is therefore confined to the tank tops, interior of tanks and coal bunkers.

155. Method of applying protective coatings.

(a) **Paint.** The surface to be painted must be clean and dry. The presence of rust, dirt, grease or moisture will prevent the adhesion of the paint. If rust is present, rusting will continue and lift the paint off. Any good hard paint on the surface may be left there provided it is thoroughly cleansed before any paint is applied. This is of the utmost importance. The paint should be applied in a thin uniform coat and ample time should be allowed for one coat to dry before the next one is applied. The last coat should be given ample time to form a hard dry surface before it is subjected to any abrasive action such as walking or handling cargo. Most bottom paints are such that the last coat should not be applied more than twenty-four hours before the ship is floated.

(b) **Cement.** The surface must be absolutely clean but need not be dry; no old paint, grease, dirt, rust, or other foreign substance may be left on the steel. The other requirements for the application of paints apply equally to the application of cement.

(c) **Bituminous compositions.** The surface must be absolutely clean, dry metal or proper adherence will not be obtained. The other requirements for the application of paints apply equally to the application of these compositions. The first coat a thin liquid, called bituminous solution, is applied with an ordinary paint brush. The second coat, called bituminous enamel, much thicker is applied hot to a thickness of about $\frac{1}{4}$ ".

(d) **Requirements of the American Bureau.** The top plating of tanks where ceiled is to be covered with Stockholm tar put on hot and well sprinkled with cement powder. All steel or iron work should receive at least two coats of good oil paint and no outside steel work such as shell plating, etc., should be painted until shortly before the vessel is launched in order that the removal of the mill oxide or scale may be assisted by a full exposure to the weather during the construction of the vessel. All faying surfaces throughout the structure of the vessel are to be well coated with red lead or other approved composition.

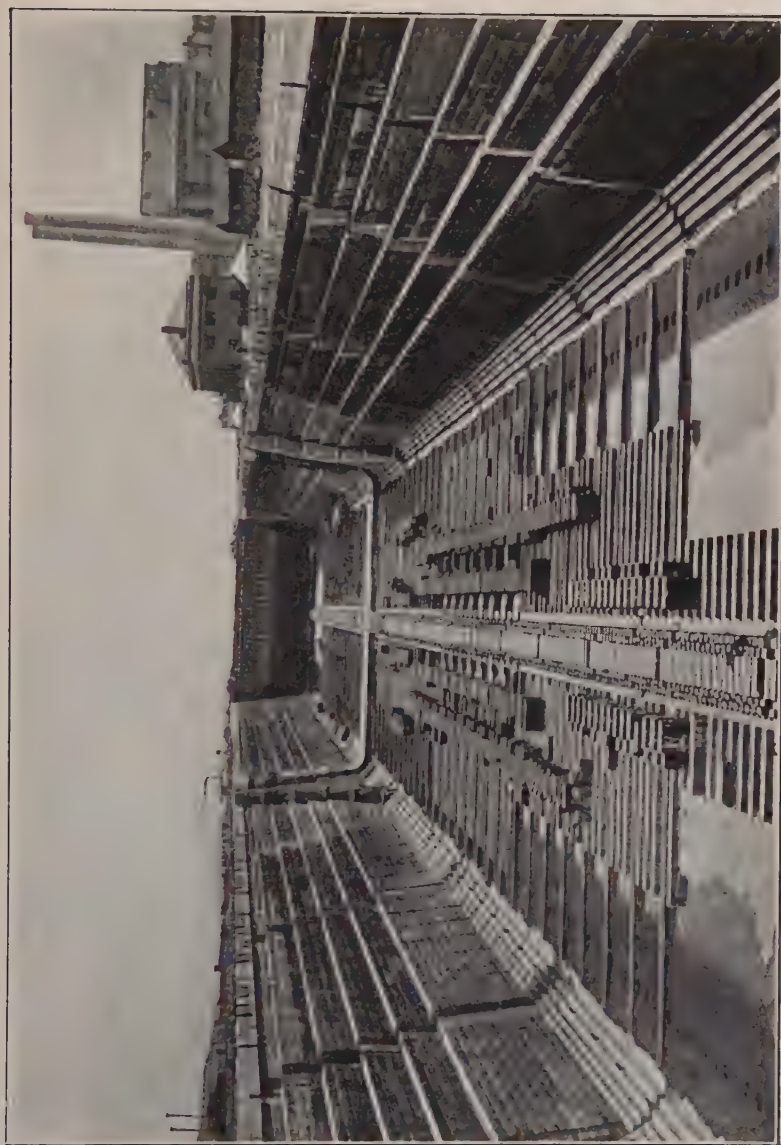


FIG. 54.—GRAVING DOCK.

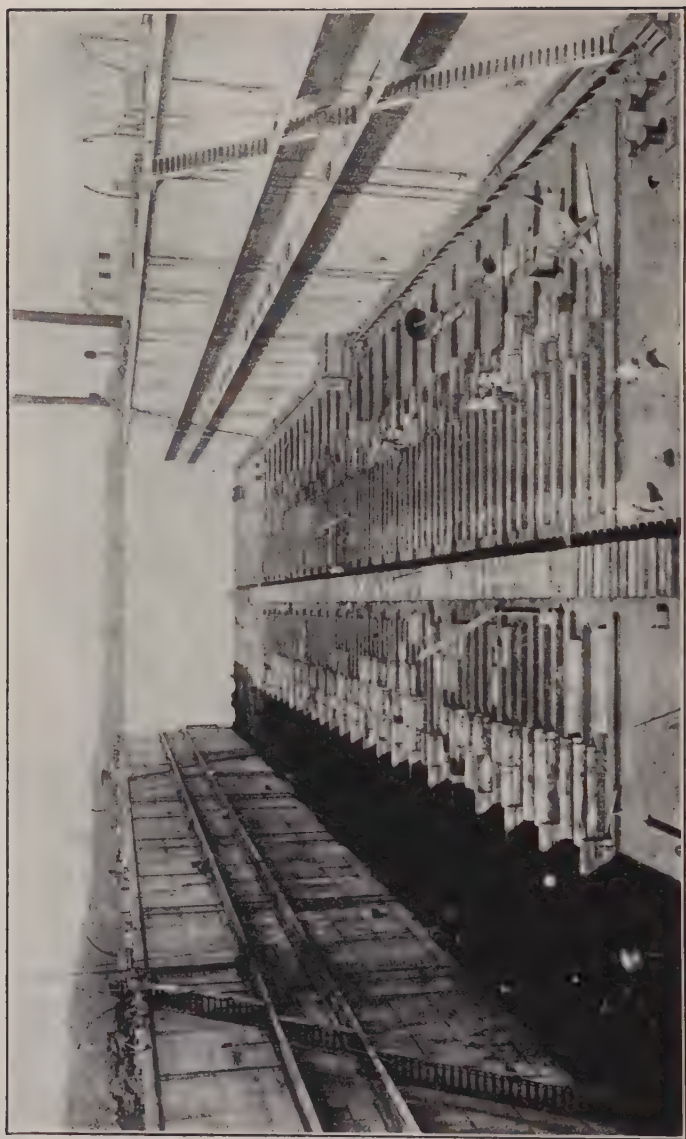


FIG. 55.—FLOATING DOCK.

SECTION B—DOCKS AND DOCKING

156. Kinds of dry docks. There are three forms of dry docks in common use, graving docks, floating dry docks and marine railways. A graving dock is shown in Fig. 54. It is an excavated basin having one end adjacent to the ship channel which may be closed watertight. A floating dock is shown in Fig. 55. It is a large floating structure having U-shaped sections, divided into a number of

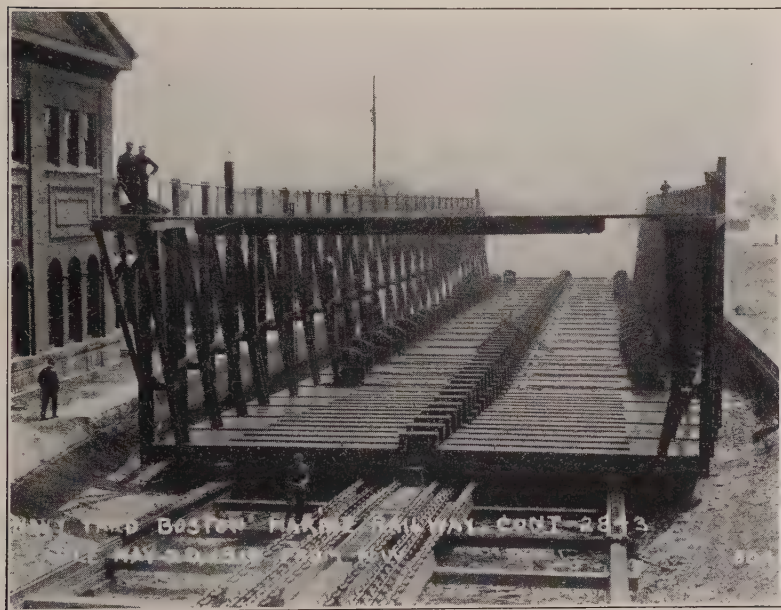


FIG. 56.—MARINE RAILWAY.

watertight compartments. The dock is also usually built in sections so that it can dock itself piecemeal. Both of these types of docks have pumps for emptying the water and valves for flooding. The essential difference in their operation is that in the graving dock the ship being docked merely grounds on the dock blocking when the water is pumped down, the dock remaining stationary. In the case of the floating dock, the ship remains stationary until she

grounds, the dock rising under her by expelling water admitted to sink it.

Fig. 56 shows a marine railway in use. It consists of two or more parallel tracks which extend from the shore above water out into the water. These tracks have a constant inclination to the horizontal. On these tracks are a number of rollers which carry the cradle, a structure having a level deck for placing the docking blocks and an elevated operating platform on each side running its entire length. At the head of the tracks is a windlass which moves the cradle in or out by means of an endless chain.

All of these dry docks have a center row of blocks known as keel blocks which support the ship along the keel while in dock. There are more widely spaced blocks, known as pull blocks or bilge blocks. These are built up to the proper height to make contact with the ship at the turn of the bilge and are used simply to steady her, i.e. hold her erect. Shores from the dock side to the side plating are placed for the same purpose. Along the coping of the dock are bollards for securing the lines and at certain locations capstans for heaving in on them. Most graving docks also have cranes for handling material. The seaward end of a graving dock may be closed by a caisson, which can be floated out of the way and sunk in a groove in the dry dock to make a watertight joint, or by gates.

157. Operation of docks.

(a) **Graving dock.** The following are the steps in docking a ship in a graving dock assuming the dock dry and caisson in place or gates closed.

(1) The blocking is arranged to conform to the ship's docking plan, properly secured in place, and shores of the proper length prepared.

(2) The dock is flooded.

(3) When the water in the dock is the same as that outside, the caisson is removed by pumping out water ballast or the gates are opened.

(4) The vessel is hauled into the dock and accurately moored in the position she is to occupy. There is usually a head line for

hauling in and four lines on each side to properly control the position of the ship in the dock.

(5) The caisson is sunk in the caisson groove or the gates are closed.

(6) The water is pumped out of the dock. When the ship is just landed on the keel blocks, the bilge blocks are hauled and the shores set up.

(7) When it is desired to undock the ship the dock is flooded, caisson removed or gates opened and the ship hauled out.

(b) Floating dock. The docking blocks are first arranged for the vessel to be docked. The dock tanks are then filled thus submerging the dock to such a depth that the vessel may be floated into it. The vessel is hauled into position and centered and the dock tanks are pumped out thus raising dock, and lifting the vessel clear of the water. The reverse operation is followed for undocking.

(c) Marine railway. The docking blocks are first arranged on the deck of the cradle for the vessel to be docked. The cradle is then hauled out until there is sufficient water over the keel blocks and the vessel to be docked is then hauled into the cradle, centered and secured in position. The cradle is then hauled in and the vessel grounded on the blocking.

158. Precautions in docking. Merchant ships should be docked empty because the hull structure is not designed to stand the excessive stresses set up when the laden ship is supported only along the keel and because most docks charge for cargo in the ship when she is docked. Other precautions to be observed by the master of a ship in docking and undocking are:

(a) See that the vessel is on an even keel and in approximately the designed trim before entering the dock. (The trim should generally not exceed one foot for every hundred feet of length of the ship.)

(b) See that there are no large free water or oil surfaces in the ship's tanks.

(c) See that sufficient men are stationed on the lines.

(d) See that the main engines are secured.

(e) Do not shift weights (cargo, feed water or oil) while docked.

(f) See that connections to the fire main are made to the dock fire system.

(g) See that all water lines which are exposed to freezing temperatures in cold weather are drained.

(h) See that connections for fresh water, compressed air, steam, and electricity are made from the dock if the boilers and auxiliaries on board are secured.

(i) See that all sea valves which have been opened or repaired while in dock are properly closed before undocking. These valves should be closed each night while in dock, if practicable.

(j) Do not turn over the main engines while in dock until the propellers are seen to be clear.

(k) See that all connections to the dock are cleared before undocking.

(l) See that all air ports are closed before undocking.

(m) Station a man at each sea valve while undocking, to keep a lookout for leaky valves.

(n) After undocking keep a watch for leaks on all parts of the under-water body which have been opened or repaired.

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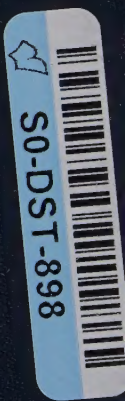
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